US010013058B2

(12) United States Patent
Puskarich et al.

(10) **Patent No.: US 10,013,058 B2**
(45) **Date of Patent: Jul. 3, 2018**

(54) **TOUCH-BASED USER INTERFACE WITH HAPTIC FEEDBACK**

(75) Inventors: **Paul G. Puskarich**, Palo Alto, CA (US); **Michael Pilliod**, San Francisco, CA (US)

(73) Assignee: **Apple Inc.**, Cupertino, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 455 days.

(21) Appl. No.: **12/887,455**

(22) Filed: **Sep. 21, 2010**

(65) **Prior Publication Data**

US 2012/0068957 A1 Mar. 22, 2012

(51) **Int. Cl.**

G06F 3/045	(2006.01)
G06F 3/01	(2006.01)
G06F 3/0354	(2013.01)
G06F 3/041	(2006.01)
H01L 41/09	(2006.01)
H01L 41/37	(2013.01)

(52) **U.S. Cl.**

CPC ***G06F 3/016*** (2013.01); ***G06F 3/03547*** (2013.01); ***G06F 3/041*** (2013.01); ***H01L 41/0986*** (2013.01); ***H01L 41/37*** (2013.01); *Y10T 29/42* (2015.01)

(58) **Field of Classification Search**

CPC G06F 3/016; G06F 3/03547; G06F 3/041; G06F 3/011; H01L 41/0986; H01L 41/37; B06B 1/0629

USPC 345/173–176, 168; 310/317; 340/407.2; 324/713

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,001,049	A	9/1961	Didier
3,390,287	A	6/1968	Sonderegger
3,419,739	A	12/1968	Clements
4,236,132	A	11/1980	Zissimopoulos
4,412,148	A	10/1983	Klicker et al.
4,414,984	A	11/1983	Zarudiansky
4,695,813	A	9/1987	Nobutoki et al.
4,975,616	A	12/1990	Park
5,010,772	A	4/1991	Bourland
5,245,734	A	9/1993	Issartel

(Continued)

FOREIGN PATENT DOCUMENTS

AU	2015100710	7/2015
AU	2016100399	5/2016

(Continued)

OTHER PUBLICATIONS

International Search Report and Written Opinion, PCT/US2011/048808, 23 pages, dated Apr. 2, 2012.

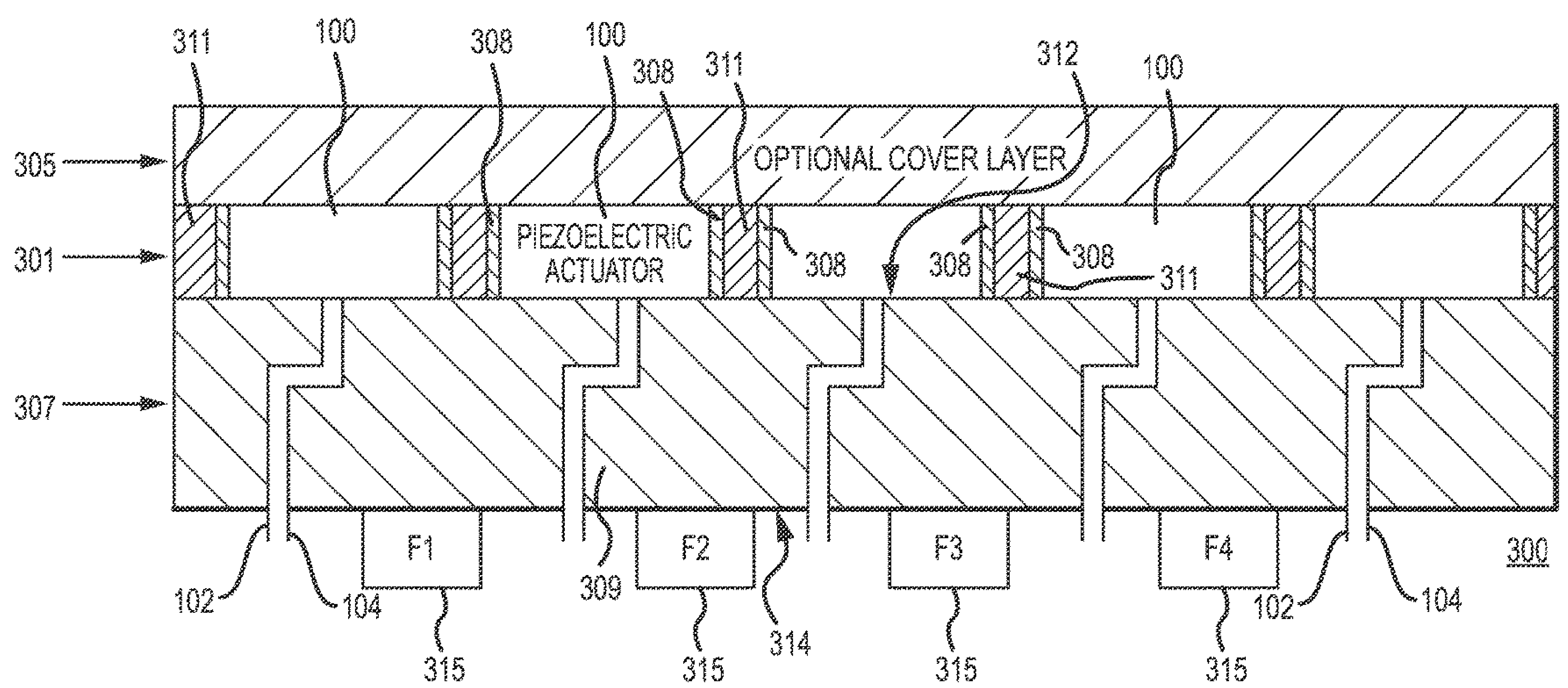
(Continued)

Primary Examiner — Kumar Patel
Assistant Examiner — Kuo Woo
(74) *Attorney, Agent, or Firm* — Brownstein Hyatt Farber Screck, LLP

(57) **ABSTRACT**

One embodiment of a touch-based user interface may include a haptic feedback layer with one or more actuators configured to supply a haptic feedback. The one or more actuators may be embedded in a nonconductive material. The touch-based user interface may further include a printed circuit board layer underlying the haptic feedback layer. The printed circuit board layer may include one or more conductive traces configured to supply a voltage to the one or more actuators.

20 Claims, 19 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

5,283,408	A	2/1994	Chen
5,293,161	A	3/1994	MacDonald et al.
5,317,221	A	5/1994	Kubo et al.
5,365,140	A	11/1994	Ohya et al.
5,434,549	A	7/1995	Hirabayashi et al.
5,436,622	A	7/1995	Gutman et al.
5,510,584	A	4/1996	Norris
5,510,783	A	4/1996	Findlater et al.
5,513,100	A	4/1996	Parker et al.
5,587,875	A	12/1996	Sellers
5,590,020	A	12/1996	Sellers
5,602,715	A	2/1997	Lempicki et al.
5,619,005	A	4/1997	Shibukawa et al.
5,621,610	A	4/1997	Moore et al.
5,625,532	A	4/1997	Sellers
5,629,578	A	5/1997	Winzer et al.
5,635,928	A	6/1997	Takagi et al.
5,718,418	A	2/1998	Gugsch
5,739,759	A	4/1998	Nakazawa et al.
5,742,242	A	4/1998	Sellers
5,783,765	A	7/1998	Muramatsu
5,793,605	A	8/1998	Sellers
5,812,116	A	9/1998	Malhi
5,813,142	A	9/1998	Demon
5,818,149	A	10/1998	Safari et al.
5,896,076	A	4/1999	Van Namen
5,907,199	A	5/1999	Miller
5,951,908	A	9/1999	Cui et al.
5,959,613	A	9/1999	Rosenberg et al.
5,973,441	A	10/1999	Lo et al.
5,982,304	A	11/1999	Selker et al.
5,982,612	A	11/1999	Roylance
5,995,026	A	11/1999	Sellers
5,999,084	A	12/1999	Armstrong
6,069,433	A	5/2000	Lazarus et al.
6,078,308	A	6/2000	Rosenberg et al.
6,127,756	A	10/2000	Iwaki
6,135,886	A	10/2000	Armstrong
6,218,966	B1	4/2001	Goodwin
6,220,550	B1	4/2001	McKillip, Jr.
6,222,525	B1	4/2001	Armstrong
6,252,336	B1	6/2001	Hall
6,342,880	B2	1/2002	Rosenberg et al.
6,351,205	B1	2/2002	Armstrong
6,373,465	B2	4/2002	Jolly et al.
6,408,187	B1	6/2002	Merriam
6,411,276	B1	6/2002	Braun et al.
6,429,849	B1	8/2002	An
6,438,393	B1	8/2002	Surronen
6,444,928	B2	9/2002	Okamoto et al.
6,455,973	B1	9/2002	Ineson
6,465,921	B1	10/2002	Horng
6,552,404	B1	4/2003	Hynes
6,552,471	B1	4/2003	Chandran et al.
6,557,072	B2	4/2003	Osborn
6,642,857	B1	11/2003	Schediwy
6,693,626	B1	2/2004	Rosenberg
6,717,573	B1	4/2004	Shahoian et al.
6,809,462	B2	10/2004	Pelrine et al.
6,809,727	B2	10/2004	Piot et al.
6,864,877	B2	3/2005	Braun et al.
6,906,697	B2	6/2005	Rosenberg
6,906,700	B1	6/2005	Armstrong
6,906,703	B2	6/2005	Vablais et al.
6,952,203	B2	10/2005	Banerjee et al.
6,954,657	B2	10/2005	Bork et al.
6,963,762	B2	11/2005	Kaaresoja et al.
6,995,752	B2	2/2006	Lu
7,005,811	B2	2/2006	Wakuda et al.
7,016,707	B2	3/2006	Fujisawa et al.
7,022,927	B2	4/2006	Hsu
7,023,112	B2	4/2006	Miyamoto et al.
7,081,701	B2	7/2006	Yoon et al.
7,121,147	B2	10/2006	Okada
7,123,948	B2	10/2006	Nielsen
7,130,664	B1	10/2006	Williams
7,136,045	B2	11/2006	Rosenberg et al.
7,161,580	B2	1/2007	Bailey et al.
7,162,928	B2	1/2007	Shank et al.
7,170,498	B2	1/2007	Huang
7,176,906	B2	2/2007	Williams et al.
7,182,691	B1	2/2007	Schena
7,194,645	B2	3/2007	Bieswanger et al.
7,217,891	B2	5/2007	Fischer et al.
7,218,310	B2	5/2007	Tierling et al.
7,219,561	B2	5/2007	Okada
7,253,350	B2	8/2007	Noro et al.
7,333,604	B2	2/2008	Zernovizky et al.
7,334,350	B2	2/2008	Ellis
7,348,968	B2	3/2008	Dawson
7,388,741	B2	6/2008	Konuma et al.
7,392,066	B2	6/2008	Hapamas
7,423,631	B2	9/2008	Shahoian et al.
7,446,752	B2	11/2008	Goldenberg et al.
7,469,595	B2	12/2008	Kessler et al.
7,495,358	B2	2/2009	Kobayashi et al.
7,508,382	B2	3/2009	Denoue et al.
7,561,142	B2	7/2009	Shahoian et al.
7,562,468	B2	7/2009	Ellis
7,569,086	B2	8/2009	Kikuchi et al.
7,575,368	B2	8/2009	Guillaume
7,586,220	B2	9/2009	Roberts
7,619,498	B2	11/2009	Miura
7,639,232	B2	12/2009	Grant et al.
7,641,618	B2	1/2010	Noda et al.
7,675,253	B2	3/2010	Dorel
7,675,414	B2	3/2010	Ray
7,679,611	B2	3/2010	Schena
7,707,742	B2	5/2010	Ellis
7,710,399	B2	5/2010	Bruneau et al.
7,732,951	B2	6/2010	Mukaide
7,742,036	B2	6/2010	Grant et al.
7,788,032	B2	8/2010	Moloney
7,793,429	B2	9/2010	Ellis
7,793,430	B2	9/2010	Ellis
7,798,982	B2	9/2010	Zets et al.
7,868,489	B2	1/2011	Amemiya et al.
7,888,892	B2	2/2011	McReynolds et al.
7,893,922	B2	2/2011	Klinghult et al.
7,919,945	B2	4/2011	Houston et al.
7,929,382	B2	4/2011	Yamazaki
7,946,483	B2	5/2011	Miller et al.
7,952,261	B2	5/2011	Lipton et al.
7,952,566	B2	5/2011	Poupyrev et al.
7,956,770	B2	6/2011	Klinghult et al.
7,961,909	B2	6/2011	Mandella et al.
8,031,172	B2	10/2011	Kruse et al.
8,044,940	B2	10/2011	Narusawa
8,069,881	B1	12/2011	Cunha
8,077,145	B2	12/2011	Rosenberg et al.
8,081,156	B2	12/2011	Ruettiger
8,082,640	B2	12/2011	Takeda
8,098,234	B2	1/2012	Lacroix et al.
8,123,660	B2	2/2012	Kruse et al.
8,125,453	B2	2/2012	Shahoian et al.
8,141,276	B2	3/2012	Ellis
8,156,809	B2	4/2012	Tierling et al.
8,174,372	B2 *	5/2012	da Costa 340/407.2
8,179,202	B2	5/2012	Cruz-Hernandez et al.
8,188,623	B2	5/2012	Park
8,205,356	B2	6/2012	Ellis
8,210,942	B2	7/2012	Shimabukuro et al.
8,232,494	B2	7/2012	Purcocks
8,248,277	B2	8/2012	Peterson et al.
8,248,278	B2	8/2012	Schlosser et al.
8,253,686	B2	8/2012	Kyung et al.
8,255,004	B2	8/2012	Huang et al.
8,261,468	B2	9/2012	Ellis
8,270,114	B2	9/2012	Argumedo et al.
8,288,899	B2	10/2012	Park et al.
8,291,614	B2	10/2012	Ellis
8,294,600	B2	10/2012	Peterson et al.
8,315,746	B2	11/2012	Cox et al.
8,378,798	B2	2/2013	Bells et al.

(56) **References Cited**

U.S. PATENT DOCUMENTS

8,384,679 B2	2/2013	Paleczny et al.	
8,395,587 B2	3/2013	Cauwels et al.	
8,398,570 B2	3/2013	Mortimer et al.	
8,411,058 B2	4/2013	Wong et al.	
8,446,264 B2	5/2013	Tanase	
8,451,255 B2	5/2013	Weber et al.	
8,461,951 B2	6/2013	Gassmann et al.	
8,466,889 B2	6/2013	Tong et al.	
8,471,690 B2	6/2013	Hennig et al.	
8,515,398 B2	8/2013	Song et al.	
8,542,134 B2	9/2013	Peterson et al.	
8,545,322 B2	10/2013	George et al.	
8,547,341 B2	10/2013	Takashima et al.	
8,570,291 B2	10/2013	Motomura	
8,575,794 B2	11/2013	Lee et al.	
8,596,755 B2	12/2013	Hibi	
8,598,893 B2	12/2013	Camus	
8,599,047 B2	12/2013	Schlosser et al.	
8,599,152 B1	12/2013	Wurtenberger et al.	
8,600,354 B2	12/2013	Esaki	
8,621,348 B2	12/2013	Ramsay et al.	
8,629,843 B2	1/2014	Steeves et al.	
8,674,941 B2	3/2014	Casparian et al.	
8,680,723 B2	3/2014	Subramanian	
8,681,092 B2	3/2014	Harada et al.	
8,682,396 B2	3/2014	Yang et al.	
8,686,952 B2	4/2014	Pope et al.	
8,710,966 B2	4/2014	Hill	
8,723,813 B2	5/2014	Park et al.	
8,735,755 B2	5/2014	Peterson et al.	
8,760,273 B2	6/2014	Casparian et al.	
8,780,060 B2	7/2014	Maschmeyer et al.	
8,787,006 B2	7/2014	Golko et al.	
8,797,152 B2	8/2014	Henderson et al.	
8,798,534 B2	8/2014	Rodriguez et al.	
8,845,071 B2	9/2014	Yamamoto et al.	
8,857,248 B2	10/2014	Shih et al.	
8,861,776 B2	10/2014	Lastrucci	
8,866,600 B2	10/2014	Yang et al.	
8,890,668 B2	11/2014	Pance et al.	
8,928,621 B2	1/2015	Ciesla et al.	
8,948,821 B2	2/2015	Newham et al.	
8,970,534 B2	3/2015	Adachi et al.	
8,976,141 B2	3/2015	Myers et al.	
9,008,730 B2	4/2015	Kim et al.	
9,019,088 B2	4/2015	Zawacki et al.	
9,035,887 B1	5/2015	Prud'Hommeaux et al.	
9,072,576 B2	7/2015	Nishiura	
9,083,821 B2	7/2015	Hughes	
9,092,129 B2	7/2015	Abdo et al.	
9,098,991 B2	8/2015	Park et al.	
9,122,325 B2	9/2015	Peshkin et al.	
9,131,039 B2	9/2015	Behles	
9,134,834 B2	9/2015	Reshef	
9,158,379 B2	10/2015	Cruz-Hernandez et al.	
9,189,932 B2	11/2015	Kerdemelidis et al.	
9,201,458 B2	12/2015	Hunt et al.	
9,235,267 B2	1/2016	Pope et al.	
9,274,601 B2	3/2016	Faubert et al.	
9,274,602 B2	3/2016	Garg et al.	
9,274,603 B2	3/2016	Modarres et al.	
9,275,815 B2	3/2016	Hoffmann	
9,300,181 B2	3/2016	Maeda et al.	
9,317,116 B2	4/2016	Ullrich et al.	
9,318,942 B2	4/2016	Sugita et al.	
9,325,230 B2	4/2016	Yamada et al.	
9,357,052 B2	5/2016	Ullrich	
9,360,944 B2	6/2016	Pinault	
9,390,599 B2	7/2016	Weinberg	
9,396,434 B2	7/2016	Rothkopf	
9,405,369 B2	8/2016	Modarres et al.	
9,449,476 B2	9/2016	Lynn	
9,454,239 B2	9/2016	Elias et al.	
9,467,033 B2	10/2016	Jun et al.	
9,477,342 B2	10/2016	Daverman et al.	
9,480,947 B2	11/2016	Jiang et al.	
9,501,912 B1	11/2016	Havskjold et al.	
9,594,450 B2	7/2017	Lynn et al.	
9,779,592 B1	10/2017	Hoen	
9,934,661 B2	4/2018	Hill	
2003/0210259 A1	11/2003	Liu	
2004/0021663 A1	2/2004	Suzuki et al.	
2004/0127198 A1	7/2004	Roskind et al.	
2005/0057528 A1	3/2005	Kleen	
2005/0107129 A1	5/2005	Kaewell et al.	
2005/0110778 A1	5/2005	Ben Ayed	
2005/0118922 A1	6/2005	Endo	
2005/0217142 A1	10/2005	Ellis	
2005/0237306 A1	10/2005	Klein et al.	
2005/0248549 A1	11/2005	Dietz et al.	
2005/0258715 A1	11/2005	Schlabach	
2006/0014569 A1	1/2006	DelGiorno	
2006/0119586 A1*	6/2006	Grant	G06F 3/016 345/173
2006/0154674 A1	7/2006	Landschaft et al.	
2006/0209037 A1	9/2006	Wang et al.	
2006/0239746 A1	10/2006	Grant	
2006/0252463 A1	11/2006	Liao	
2007/0099574 A1	5/2007	Wang	
2007/0152974 A1	7/2007	Kim et al.	
2007/0178942 A1	8/2007	Sadler et al.	
2007/0188450 A1	8/2007	Hernandez et al.	
2008/0084384 A1	4/2008	Gregorio et al.	
2008/0158149 A1	7/2008	Levin	
2008/0165148 A1	7/2008	Williamson	
2008/0181501 A1	7/2008	Faraboschi	
2008/0181706 A1	7/2008	Jackson	
2008/0192014 A1	8/2008	Kent et al.	
2008/0204428 A1*	8/2008	Pierce	G06F 3/0202 345/174
2008/0252594 A1	10/2008	Gregorio et al.	
2008/0255794 A1	10/2008	Levine	
2008/0291620 A1	11/2008	DiFonzo et al.	
2009/0002328 A1	1/2009	Ullrich et al.	
2009/0115734 A1	5/2009	Fredriksson et al.	
2009/0120105 A1	5/2009	Ramsay et al.	
2009/0128503 A1	5/2009	Grant et al.	
2009/0135142 A1	5/2009	Fu et al.	
2009/0160813 A1*	6/2009	Takashima et al.	345/173
2009/0167542 A1	7/2009	Culbert et al.	
2009/0167702 A1	7/2009	Nurmi	
2009/0167704 A1	7/2009	Terlizzi et al.	
2009/0218148 A1	9/2009	Hugeback et al.	
2009/0225046 A1*	9/2009	Kim	G06F 3/016 345/173
2009/0236210 A1	9/2009	Clark et al.	
2009/0267892 A1	10/2009	Faubert	
2009/0267920 A1	10/2009	Faubert et al.	
2009/0305744 A1	12/2009	Ullrich	
2009/0313542 A1	12/2009	Cruz-Hernandez et al.	
2009/0322496 A1*	12/2009	da Costa	G06F 3/016 340/407.2
2010/0020036 A1	1/2010	Hui et al.	
2010/0048256 A1	2/2010	Huppi et al.	
2010/0053087 A1*	3/2010	Dai	G06F 3/016 345/168
2010/0079264 A1	4/2010	Hoellwarth	
2010/0089735 A1	4/2010	Takeda et al.	
2010/0141606 A1	6/2010	Bae et al.	
2010/0152620 A1	6/2010	Ramsay et al.	
2010/0164894 A1	7/2010	Kim et al.	
2010/0188422 A1	7/2010	Shingai et al.	
2010/0194547 A1	8/2010	Terrell et al.	
2010/0225340 A1*	9/2010	Smith	G06F 3/011 324/713
2010/0231508 A1	9/2010	Cruz-Hernandez et al.	
2010/0231550 A1	9/2010	Cruz-Hernandez et al.	
2010/0265197 A1	10/2010	Purdy	
2010/0309141 A1	12/2010	Cruz-Hernandez et al.	
2010/0328229 A1	12/2010	Weber et al.	
2011/0012717 A1	1/2011	Pance et al.	
2011/0043454 A1*	2/2011	Modarres	B06B 1/0629 345/173
2011/0053577 A1	3/2011	Lee et al.	

(56) **References Cited**

U.S. PATENT DOCUMENTS

2011/0075835	A1	3/2011	Hill	
2011/0077055	A1	3/2011	Hill	
2011/0107958	A1	5/2011	Pance et al.	
2011/0121765	A1	5/2011	Anderson et al.	
2011/0128239	A1	6/2011	Polyakov et al.	
2011/0141052	A1*	6/2011	Bernstein et al.	345/174
2011/0148608	A1	6/2011	Grant et al.	
2011/0163985	A1	7/2011	Bae et al.	
2011/0175692	A1	7/2011	Niiyama	
2011/0193824	A1	8/2011	Modarres et al.	
2011/0203912	A1	8/2011	Niu	
2011/0248948	A1	10/2011	Griffin et al.	
2011/0260988	A1	10/2011	Colgate et al.	
2011/0263200	A1	10/2011	Thornton et al.	
2011/0291950	A1	12/2011	Tong	
2011/0304559	A1	12/2011	Pasquero	
2012/0075198	A1	3/2012	Sulem et al.	
2012/0092263	A1	4/2012	Peterson et al.	
2012/0126959	A1	5/2012	Zarrabi et al.	
2012/0127088	A1	5/2012	Pance et al.	
2012/0133494	A1	5/2012	Cruz-Hernandez et al.	
2012/0139844	A1	6/2012	Ramstein et al.	
2012/0206248	A1	8/2012	Biggs	
2012/0223824	A1	9/2012	Rothkopf	
2012/0256848	A1	10/2012	Madabusi Srinivasan	
2012/0268412	A1	10/2012	Cruz-Hernandez et al.	
2012/0274578	A1	11/2012	Snow et al.	
2012/0280927	A1	11/2012	Ludwig	
2012/0286943	A1	11/2012	Rothkopf et al.	
2012/0319827	A1	12/2012	Pance et al.	
2012/0327006	A1	12/2012	Israr et al.	
2013/0027345	A1	1/2013	Binzel	
2013/0063356	A1	3/2013	Martisauskas	
2013/0106699	A1	5/2013	Babatunde	
2013/0120290	A1	5/2013	Yumiki et al.	
2013/0124076	A1	5/2013	Bruni et al.	
2013/0181913	A1	7/2013	Cole et al.	
2013/0191741	A1	7/2013	Dickinson et al.	
2013/0207793	A1	8/2013	Weaber et al.	
2013/0217491	A1	8/2013	Hilbert et al.	
2013/0222280	A1	8/2013	Sheynblat et al.	
2013/0228023	A1	9/2013	Drasnin et al.	
2013/0261811	A1	10/2013	Yagi et al.	
2013/0300549	A1	11/2013	Hill	
2013/0300590	A1	11/2013	Dietz et al.	
2014/0035397	A1	2/2014	Endo et al.	
2014/0082490	A1	3/2014	Jung et al.	
2014/0091857	A1	4/2014	Bernstein	
2014/0143785	A1	5/2014	Mistry et al.	
2014/0197936	A1	7/2014	Biggs et al.	
2014/0232534	A1	8/2014	Birnbaum et al.	
2014/0267076	A1	9/2014	Birnbaum et al.	
2014/0267952	A1	9/2014	Sirois	
2015/0005039	A1	1/2015	Liu et al.	
2015/0040005	A1	2/2015	Faaborg	
2015/0061848	A1	3/2015	Hill	
2015/0090572	A1	4/2015	Lee et al.	
2015/0109215	A1	4/2015	Puskarich	
2015/0169059	A1	6/2015	Behles et al.	
2015/0192414	A1	7/2015	Das et al.	
2015/0194165	A1	7/2015	Faaborg et al.	
2015/0220199	A1	8/2015	Wang et al.	
2015/0227204	A1	8/2015	Gipson et al.	
2015/0296480	A1	10/2015	Kinsey et al.	
2015/0324049	A1	11/2015	Kies et al.	
2015/0349619	A1	12/2015	Degner et al.	
2016/0049265	A1	2/2016	Bernstein	
2016/0063826	A1	3/2016	Morrell et al.	
2016/0071384	A1	3/2016	Hill	
2016/0162025	A1	6/2016	Shah	
2016/0163165	A1	6/2016	Morrell et al.	
2016/0172953	A1	6/2016	Degner et al.	
2016/0195929	A1	7/2016	Martinez et al.	
2016/0196935	A1	7/2016	Bernstein	
2016/0206921	A1	7/2016	Szabados et al.	
2016/0211736	A1	7/2016	Moussette et al.	
2016/0216764	A1	7/2016	Morrell et al.	
2016/0216766	A1	7/2016	Puskarich	
2016/0231815	A1	8/2016	Moussette et al.	
2016/0233012	A1	8/2016	Lubinski et al.	
2016/0241119	A1	8/2016	Keeler	
2016/0259480	A1	9/2016	Augenbergs et al.	
2016/0306423	A1	10/2016	Uttermann et al.	
2016/0371942	A1	12/2016	Smith, IV et al.	
2017/0038905	A1	2/2017	Bijamov et al.	
2017/0070131	A1	3/2017	Degner et al.	
2017/0257844	A1	9/2017	Miller et al.	
2017/0285747	A1	10/2017	Chen	
2017/0311282	A1	10/2017	Miller et al.	
2017/0357325	A1	12/2017	Yang et al.	
2017/0364158	A1	12/2017	Wen et al.	
2018/0075715	A1	3/2018	Morrell et al.	
2018/0081441	A1	3/2018	Pedder et al.	

FOREIGN PATENT DOCUMENTS

CA	2355434		2/2002
CN	1817321		8/2006
CN	101409164		4/2009
CN	101763192		6/2010
CN	101903848		12/2010
CN	102025257		4/2011
CN	102246122		11/2011
CN	102315747		1/2012
CN	102591512		7/2012
CN	102713805		10/2012
CN	102844972		12/2012
CN	103181090		6/2013
CN	103416043		11/2013
DE	19517630		11/1996
DE	10330024		1/2005
DE	102009038103		2/2011
DE	10201115762		4/2013
EP	0483955		5/1992
EP	1047258		10/2000
EP	1686776		8/2006
EP	2060967		5/2009
EP	2073099		6/2009
EP	2194444		6/2010
EP	2264562	A3	12/2010
EP	2315186		4/2011
EP	2374430		10/2011
EP	2395414		12/2011
EP	2461228		6/2012
EP	2631746		8/2013
EP	2434555		10/2013
JP	H05301342	A2	11/1993
JP	2002199689		7/2002
JP	2002102799		9/2002
JP	200362525		3/2003
JP	2004236202		8/2004
KR	20050033909		4/2005
KR	1020100046602		5/2010
KR	1020110101516		9/2011
KR	20130024420		3/2013
TW	200518000		11/2007
TW	200951944		12/2009
TW	201145336		12/2011
TW	201218039		5/2012
TW	201425180		7/2014
WO	WO1997/16932		5/1997
WO	WO 01/059588		8/2001
WO	WO2002/073587		9/2002
WO	WO 03/038800		5/2003
WO	WO2006/057770		6/2006
WO	WO2007/114631		10/2007
WO	WO2008/075082		6/2008
WO	WO2009/038862		3/2009
WO	WO2009/068986		6/2009
WO	WO2009/097866		8/2009
WO	WO2009/122331		10/2009
WO	WO2009/150287		12/2009
WO	WO 10/085575		7/2010
WO	WO2010/087925		8/2010

(56) **References Cited**

FOREIGN PATENT DOCUMENTS

WO	WO 11/007263	1/2011
WO	WO 12/052635	4/2012
WO	WO 12/129247	9/2012
WO	WO 13/069148	5/2013
WO	WO 13/169302	11/2013
WO	WO 14/018086	1/2014
WO	WO 13/169299	11/2014
WO	WO 15/023670	2/2015

OTHER PUBLICATIONS

Hasser et al., "Preliminary Evaluation of a Shape-Memory Alloy Tactile Feedback Display," Advances in Robotics, Mechantronics, and Haptic Interfaces, ASME, DSC—vol. 49, pp. 73-80, 1993.
Hill et al., "Real-time Estimation of Human Impedance for Haptic Interfaces," Stanford Telerobotics Laboratory, Department of Mechanical Engineering, Standford University, 6 pages, at least as early as Sep. 30, 2009.
Lee et al, "Haptic Pen: Tactile Feedback Stylus for Touch Screens," Mitsubishi Electric Research Laboratories, http://wwwlmerl.com, 6 pages, Oct. 2004.
Office Action dated May 15, 2014, TW 100132478, 8 pages.
Kim et al., "Tactile Rendering of 3D Features on Touch Surfaces," UIST '13, Oct. 8-11, 2013, St. Andrews, United Kingdom, 8 pages.
European Search Report dated Jul. 7, 2015, EP 11752699.6, 7 pages.
U.S. Appl. No. 14/910,108, filed Feb. 4, 2016, Martinez et al.
U.S. Appl. No. 15/045,761, filed Feb. 17, 2016, Morrell et al.
U.S. Appl. No. 15/046,194, filed Feb. 17, 2016, Degner et al.
U.S. Appl. No. 15/047,447, filed Feb. 18, 2016, Augenbergs et al.
U.S. Appl. No. 15/102,826, filed Jun. 8, 2016 Smith et al.
U.S. Appl. No. 15/251,459, filed Aug. 30, 2016, Miller et al.
U.S. Appl. No. 15/260,047, filed Sep. 8, 2016, Degner.
U.S. Appl. No. 15/306,034, filed Oct. 21, 2016, Bijamov et al.
Astronomer's Toolbox, "The Electromagnetic Spectrum," http://imagine.gsfc.nasa.gov/science/toolbox/emspectrum1.html, updated Mar. 2013, 4 pages.
U.S. Appl. No. 15/364,822, filed Nov. 30, 2016, Chen.
U.S. Appl. No. 15/583,938, filed May 1, 2017, Hill.
Nakamura, "A Torso Haptic Display Based on Shape Memory Alloy Actuators," Massachusetts Institute of Technology, 2003, pp. 1-123.
U.S. Appl. No. 15/621,966, filed Jun. 13, 2017, Pedder et al.
U.S. Appl. No. 15/621,930, filed Jun. 13, 2017, Wen et al.
U.S. Appl. No. 15/622,017, filed Jun. 13, 2017, Yang et al.
U.S. Appl. No. 15/641,192, filed Jul. 3, 2017, Miller et al.
U.S. Appl. No. 15/800,630, filed Nov. 1, 2017, Morrell et al.
U.S. Appl. No. 13/630,867, filed Sep. 28, 2012, Bernstein.
U.S. Appl. No. 14/059,693, filed Oct. 22, 2013, Puskarich.
U.S. Appl. No. 14/165,475, filed Jan. 27, 2014, Hayskjold et al.
U.S. Appl. No. 14/493,190, filed Sep. 22, 2014, Hoen.
U.S. Appl. No. 14/512,927, filed Oct. 13, 2014, Hill.
U.S. Appl. No. 14/928,465, filed Oct. 30, 2015, Bernstein.

* cited by examiner

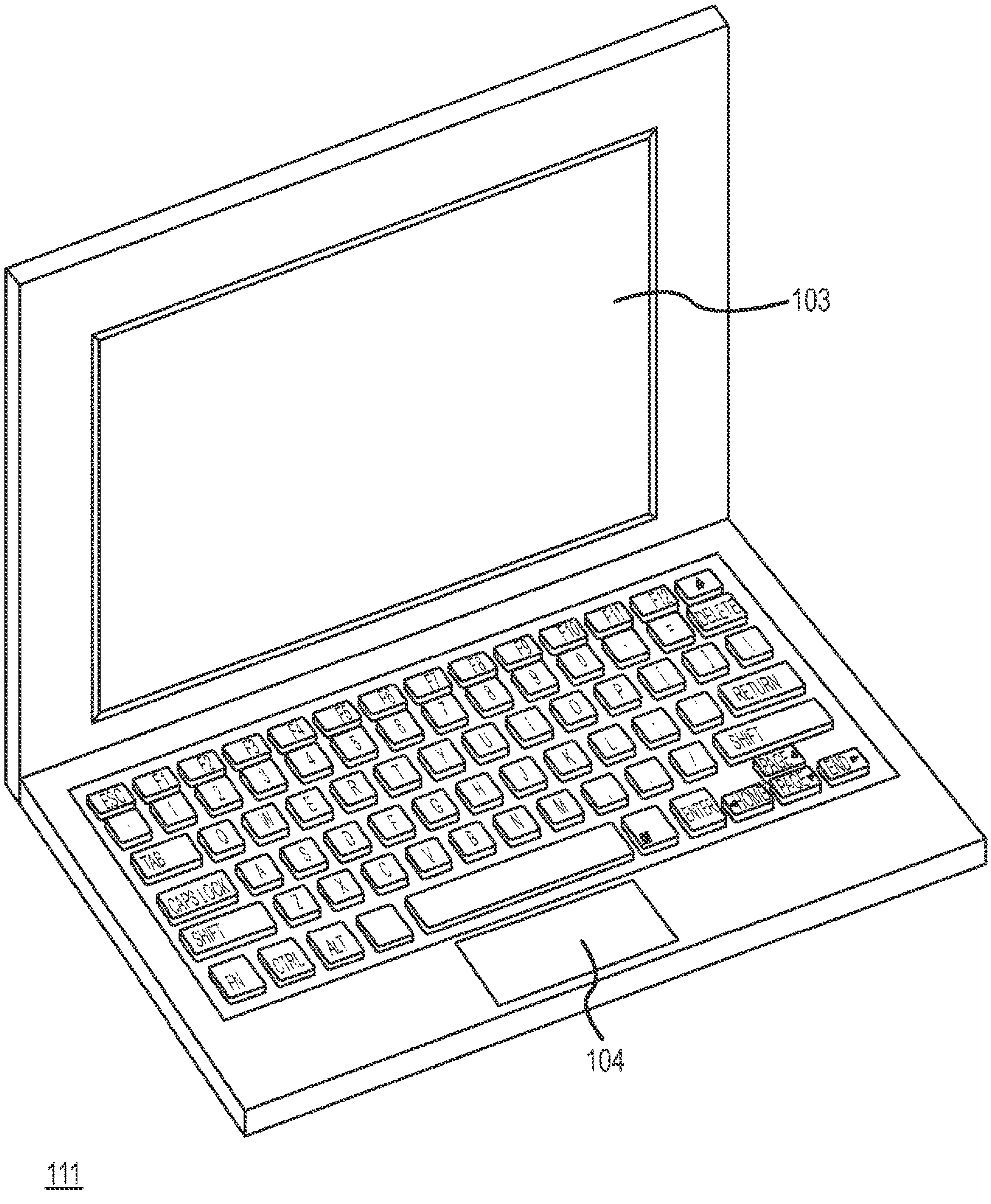


FIG.1A

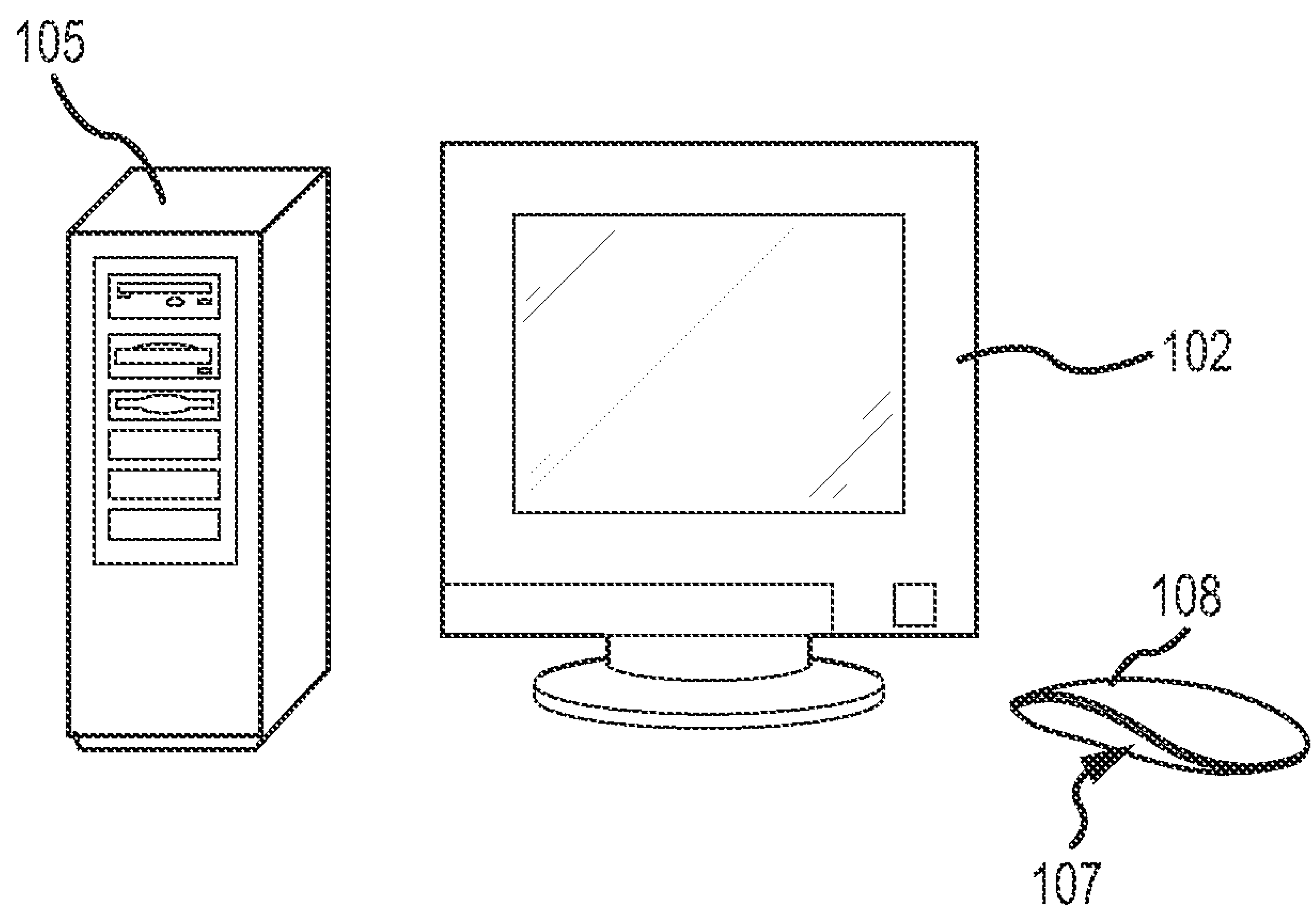


FIG.1B

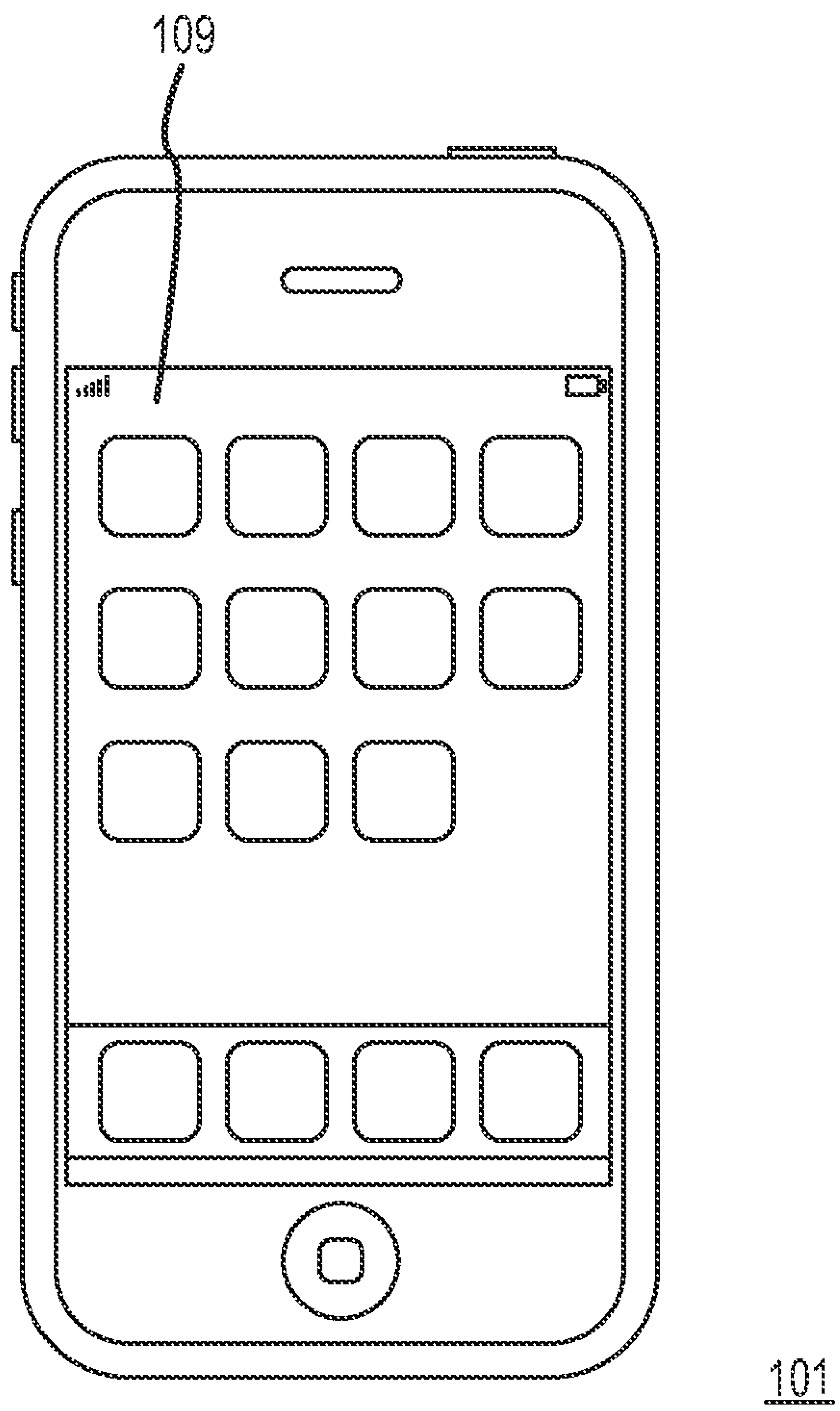


FIG.1C

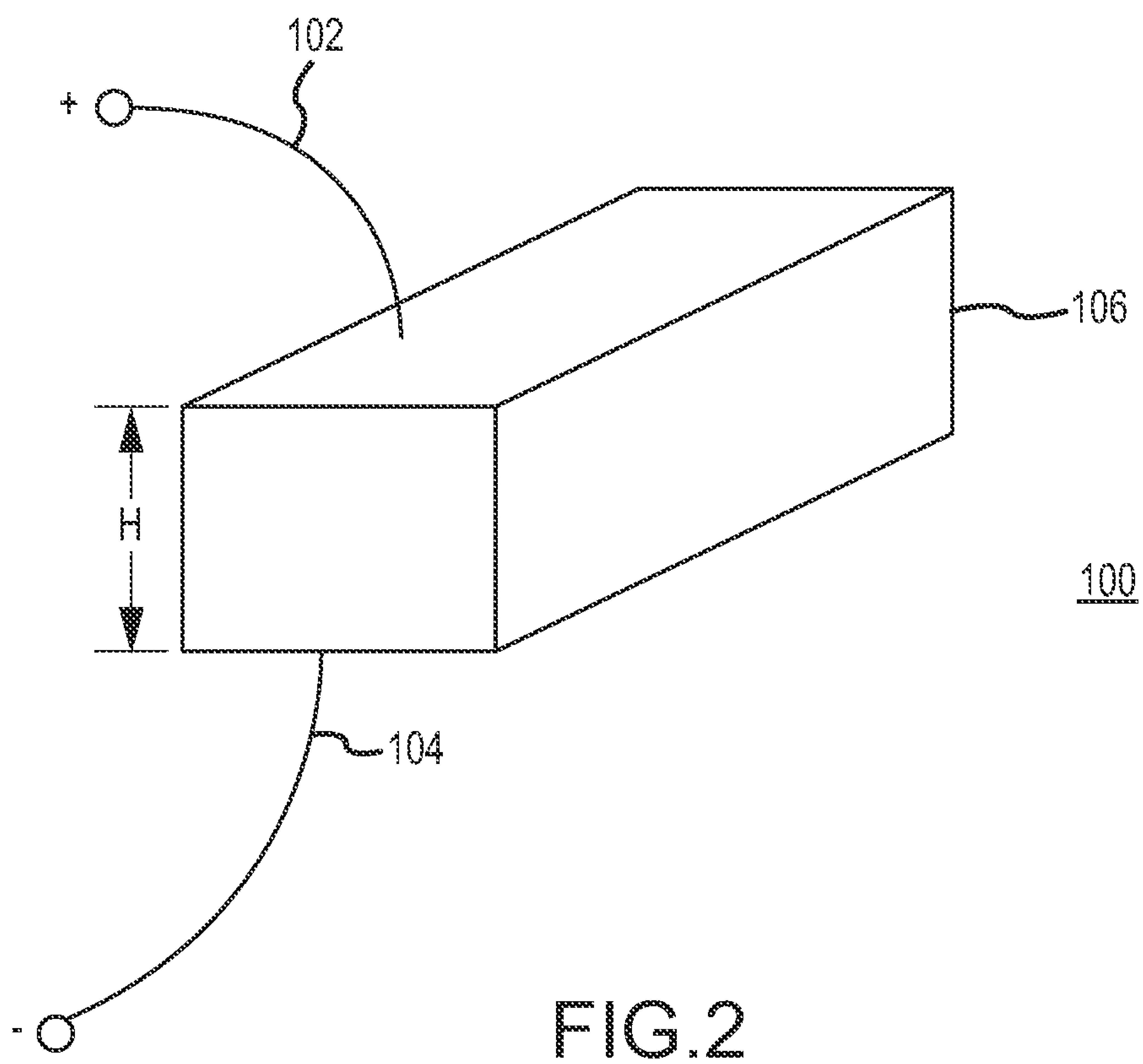


FIG.2

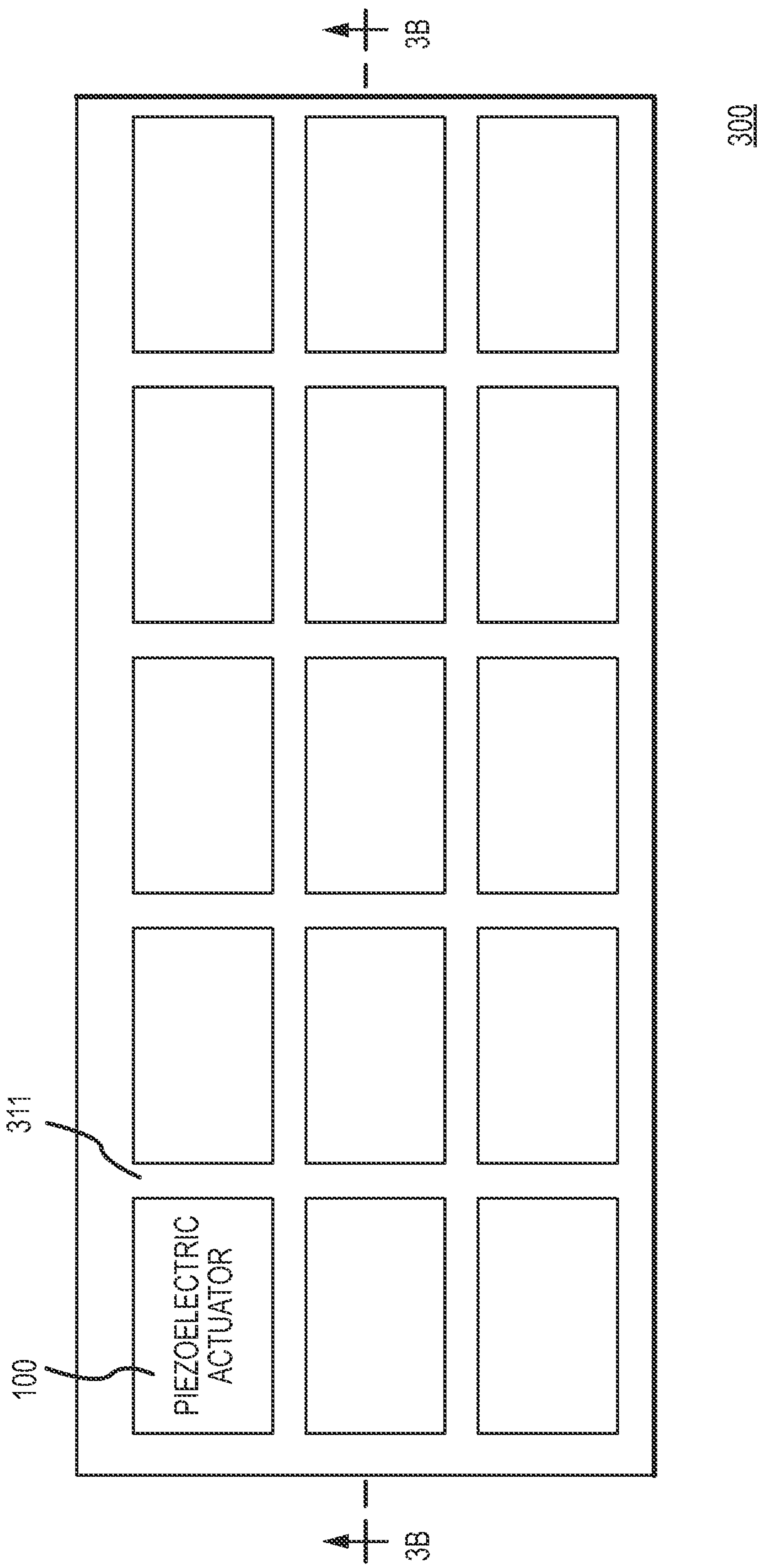


FIG.3A

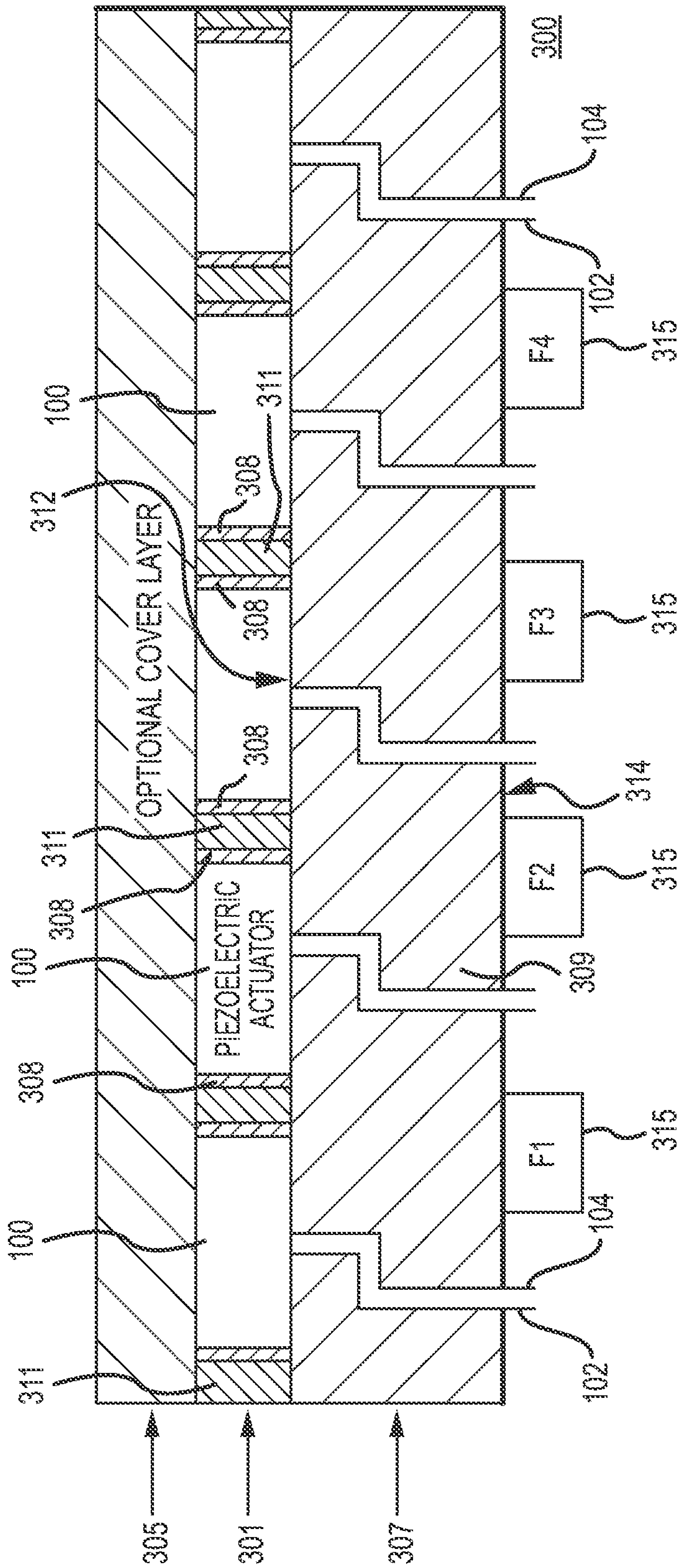

300
100
311
312
308
OPTIONAL COVER LAYER
PIEZOELECTRIC ACTUATOR
104
102
F1
F2
F3
F4
315
314
309
305
301
307

FIG.3B

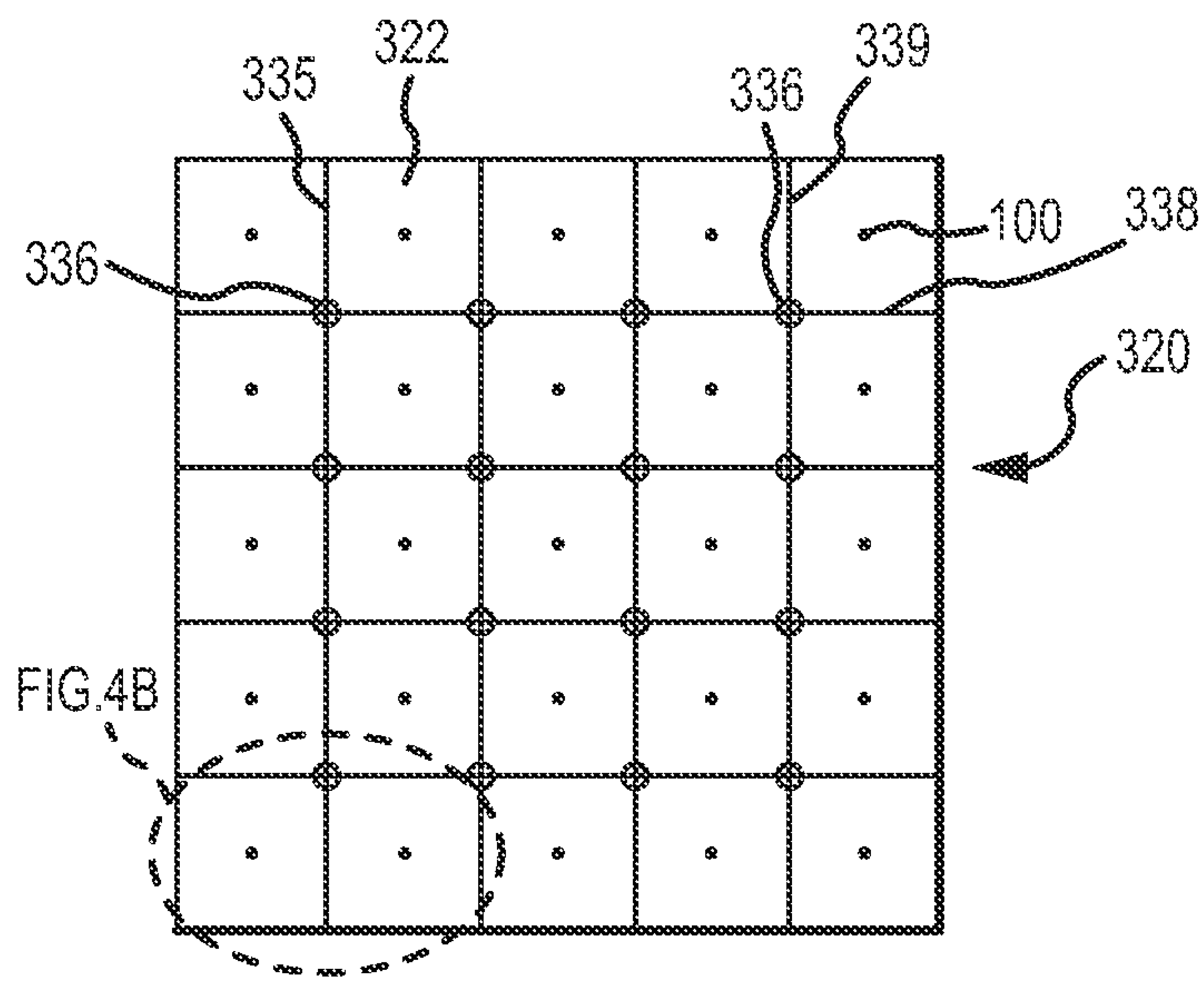


FIG.4A

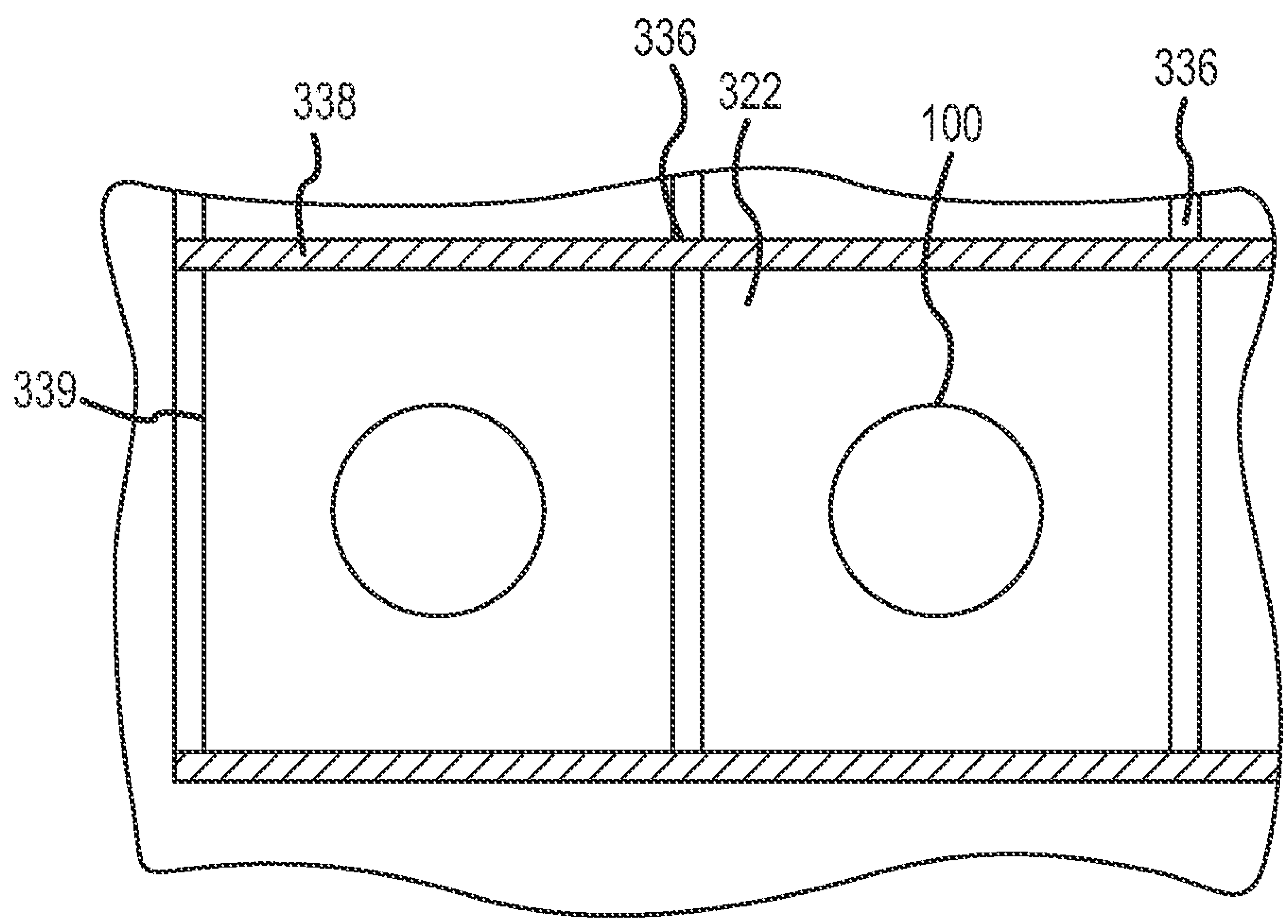


FIG.4B

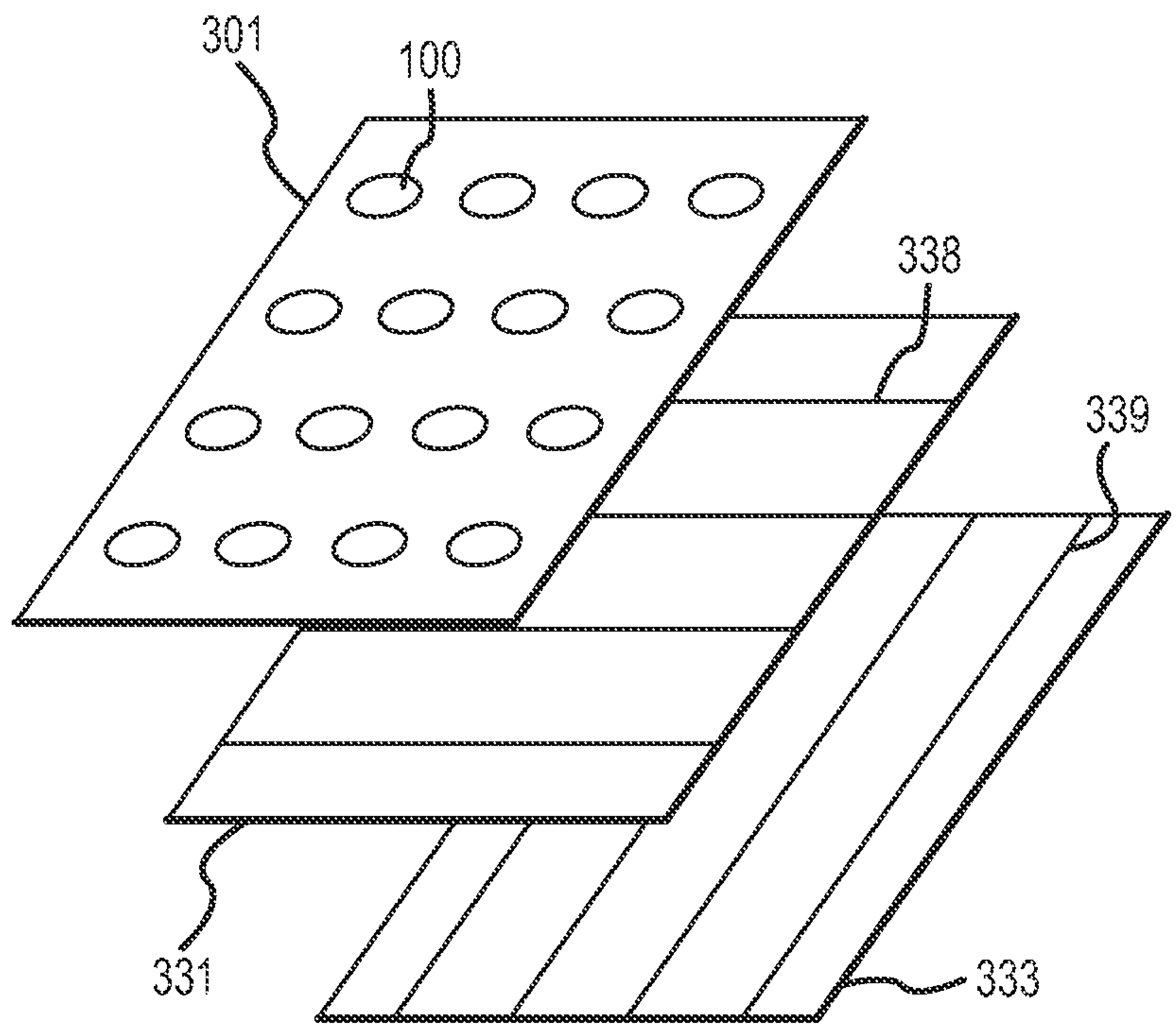


FIG.4C

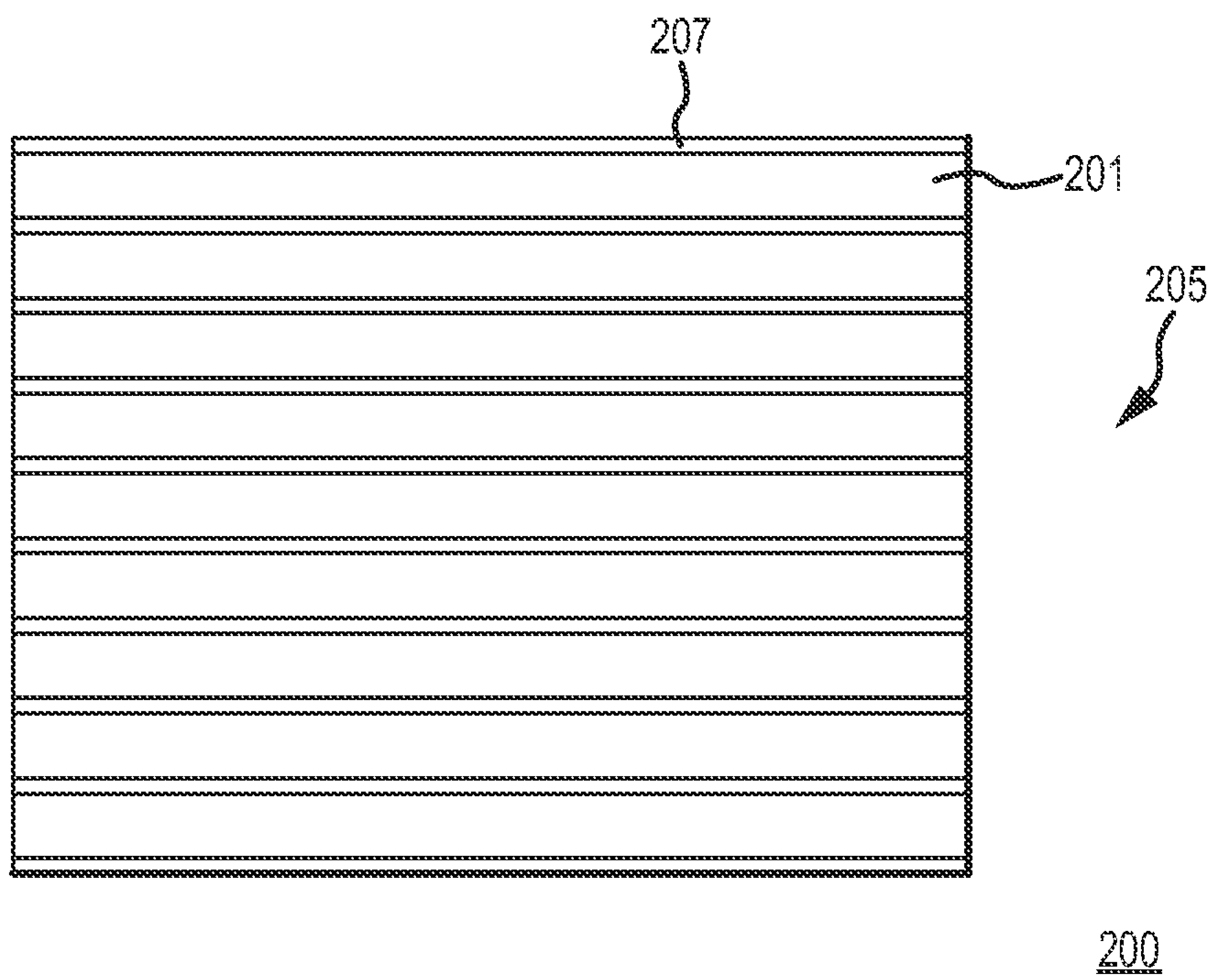


FIG.5A

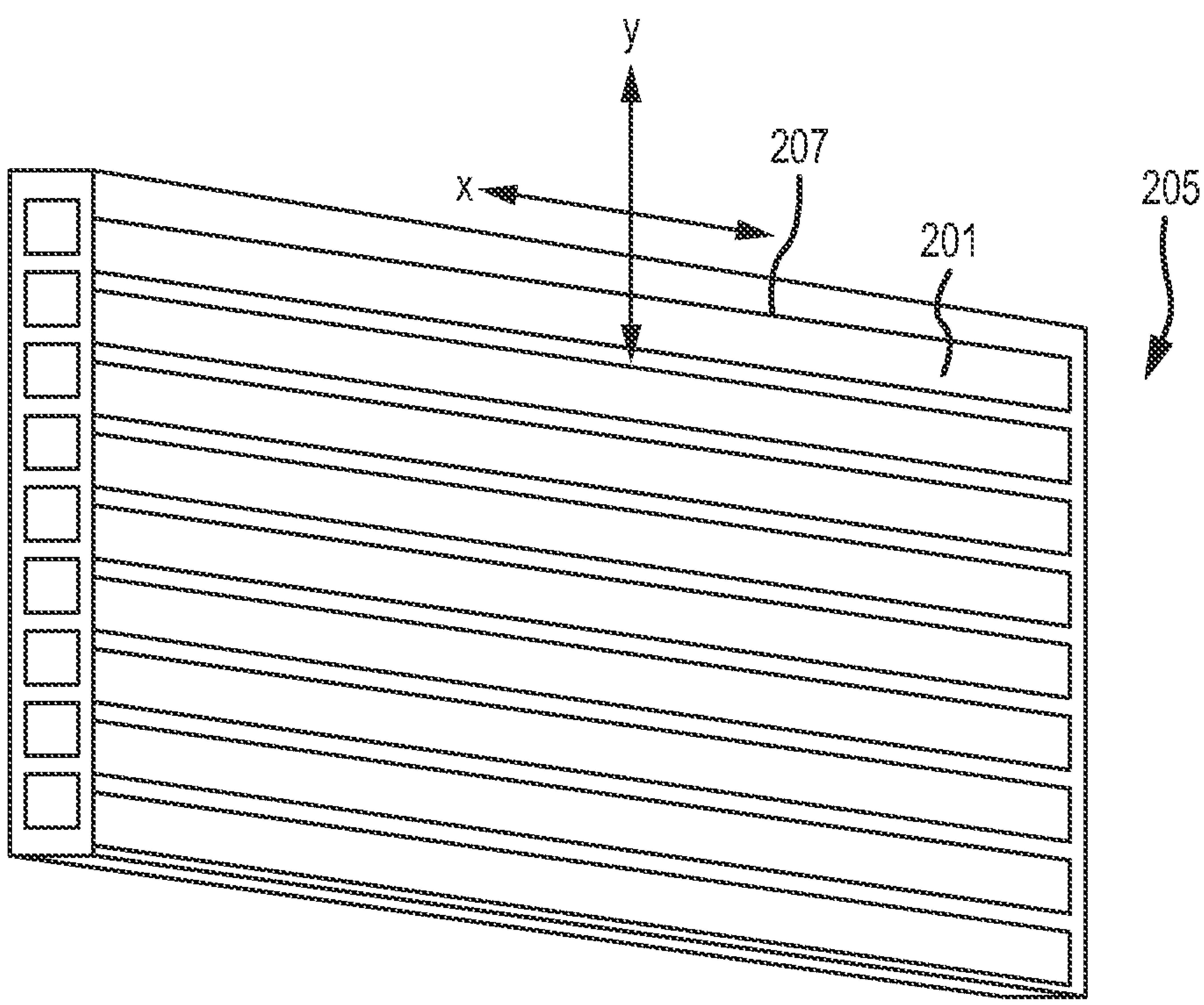


FIG.5B

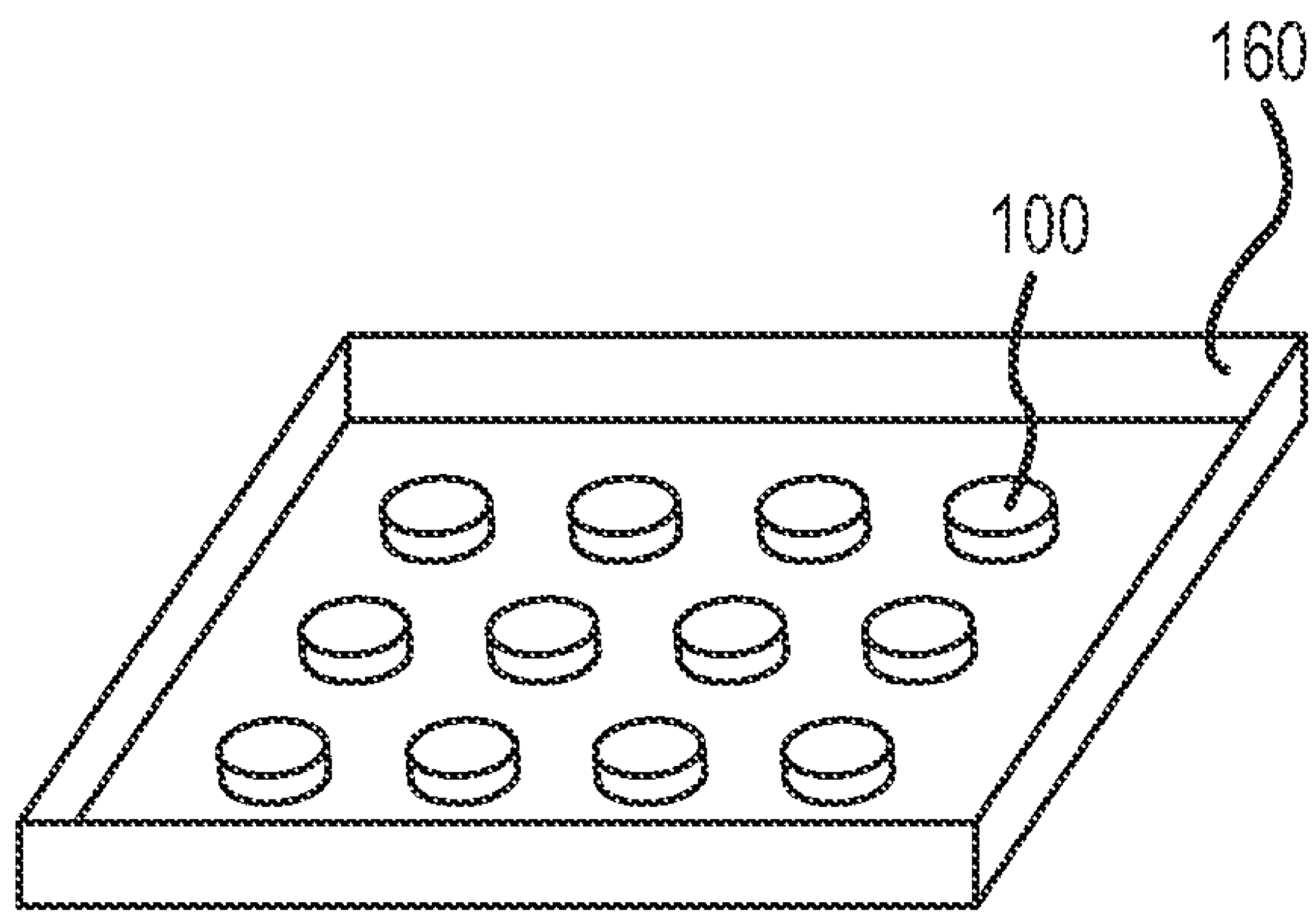


FIG.6A

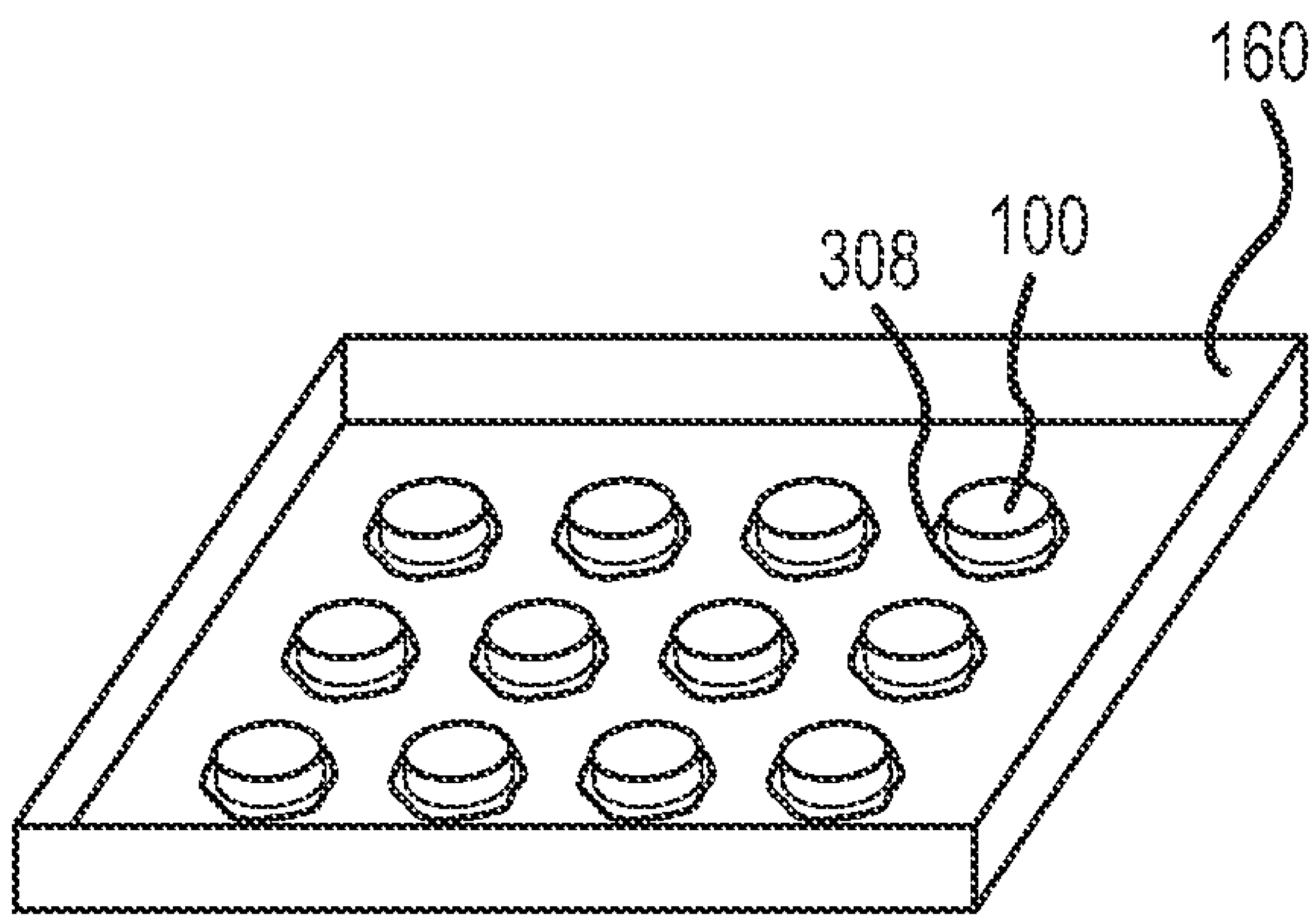


FIG.6B

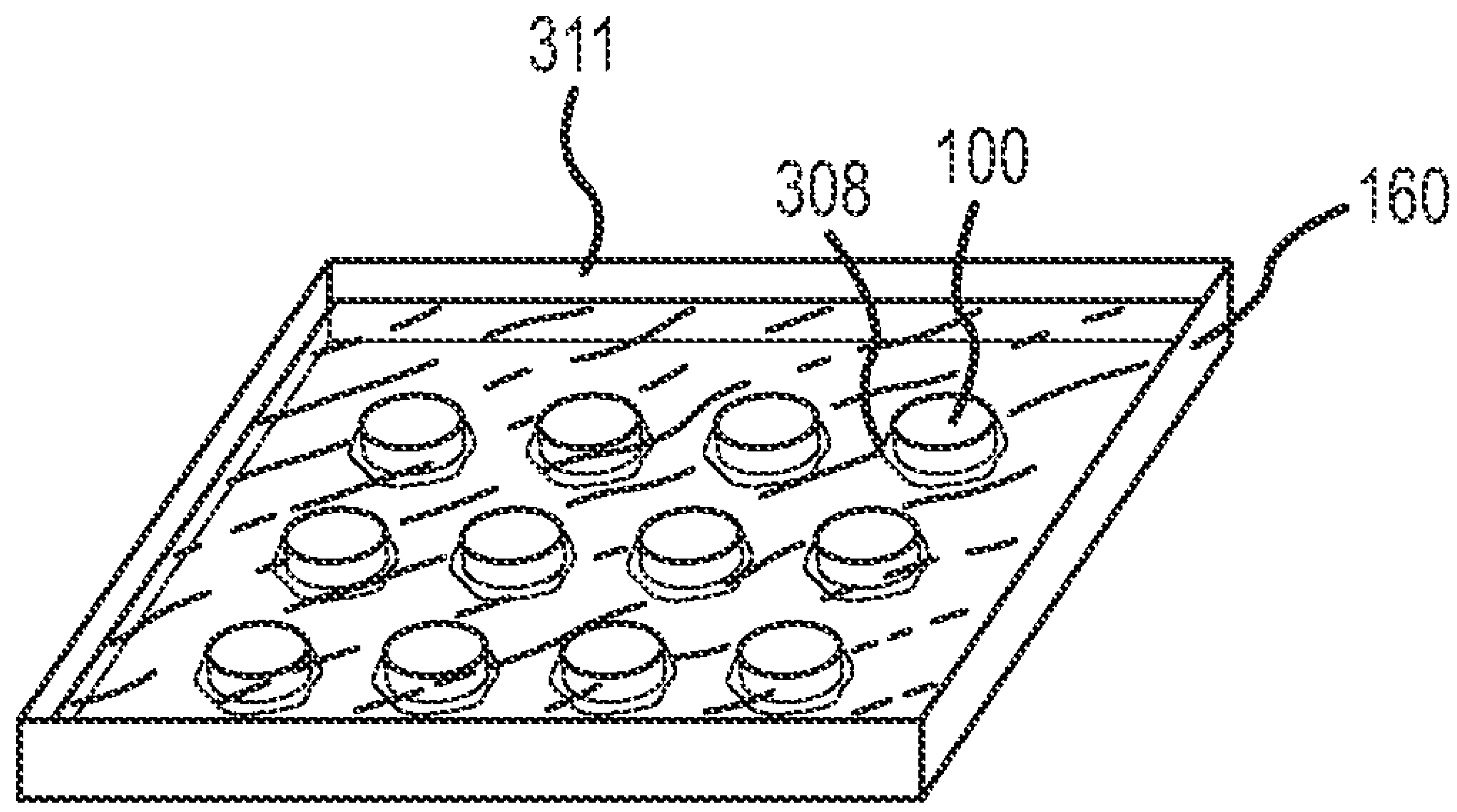


FIG.6C

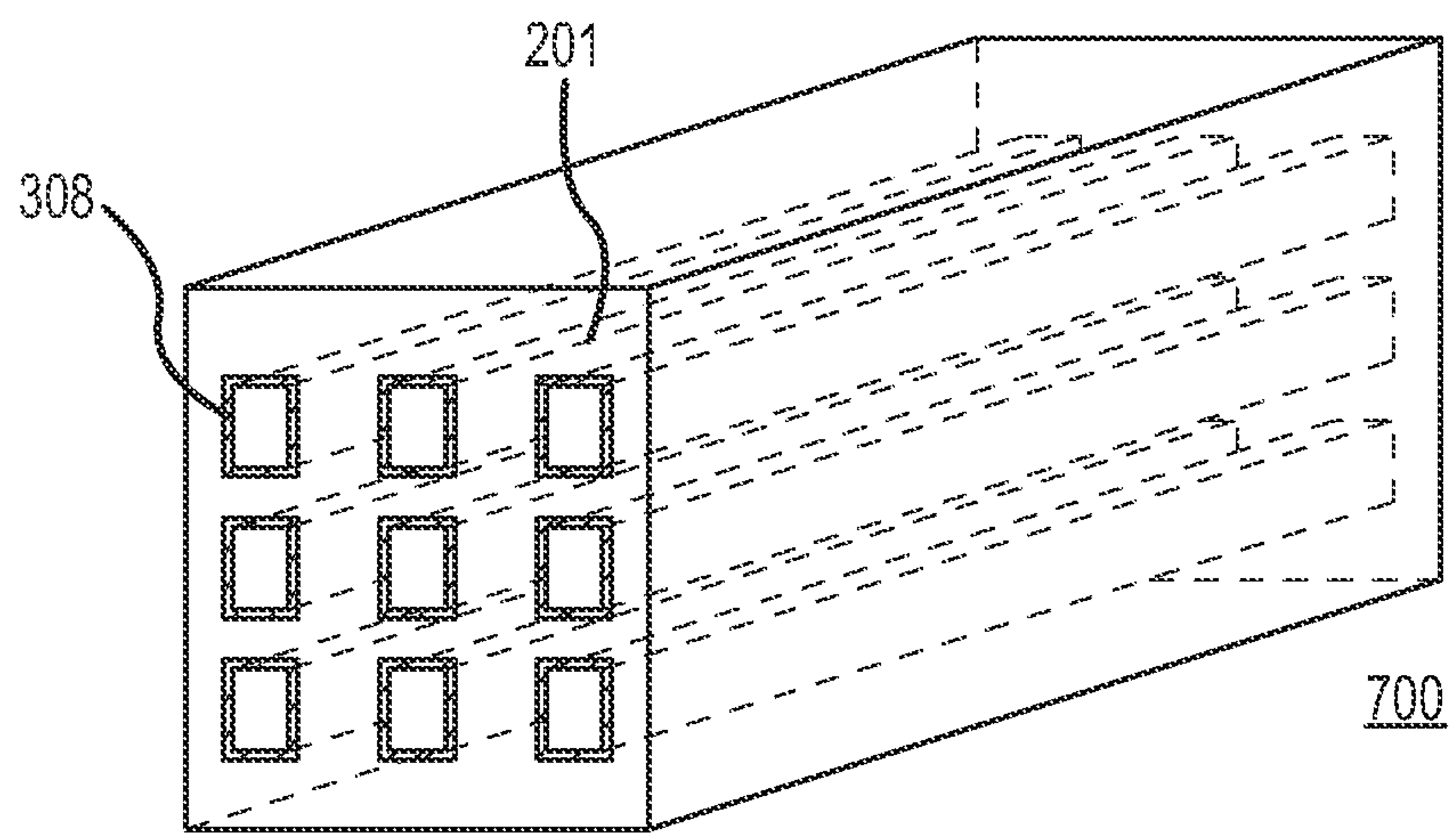


FIG.7A

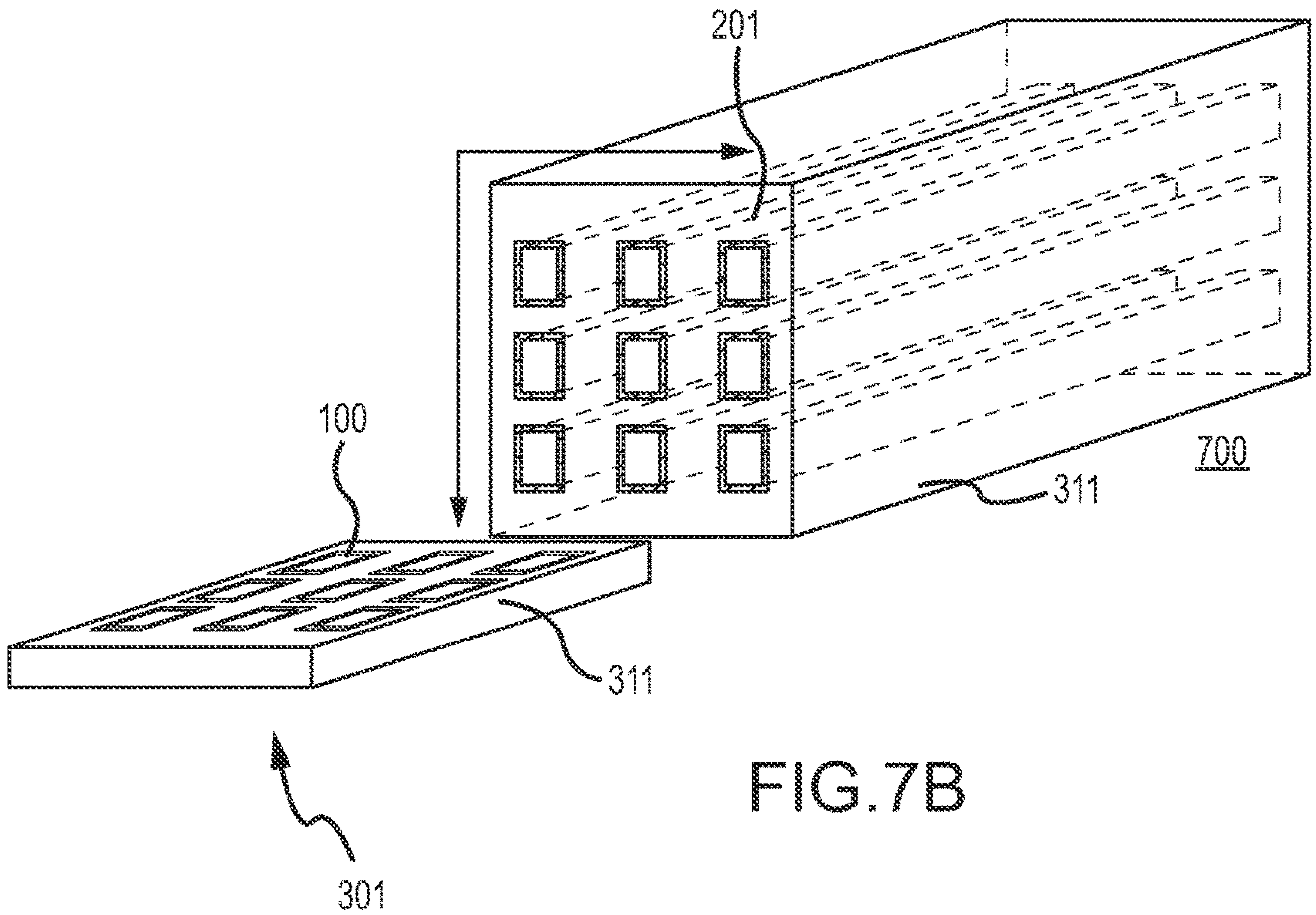


FIG.7B

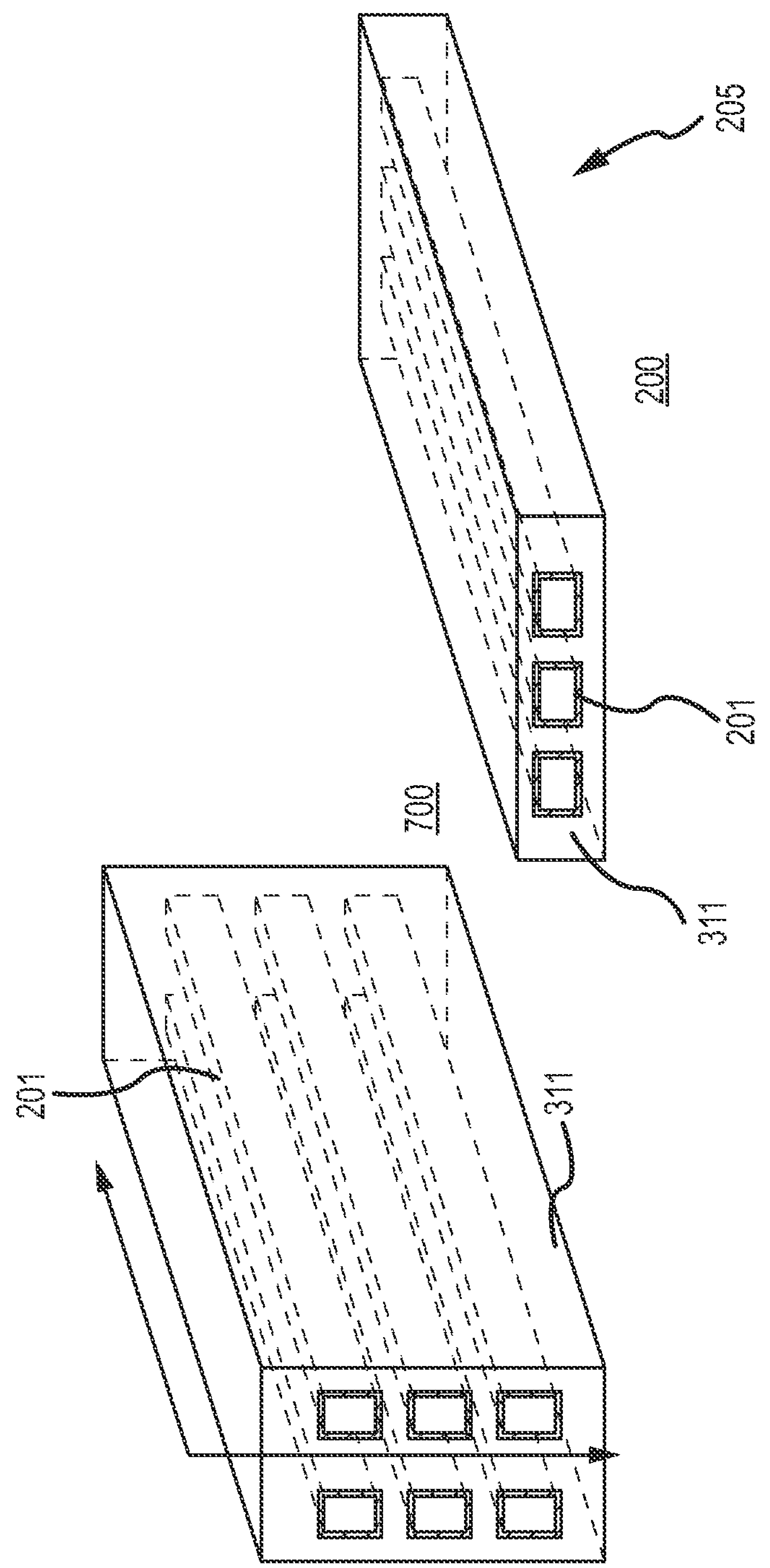


FIG.7C

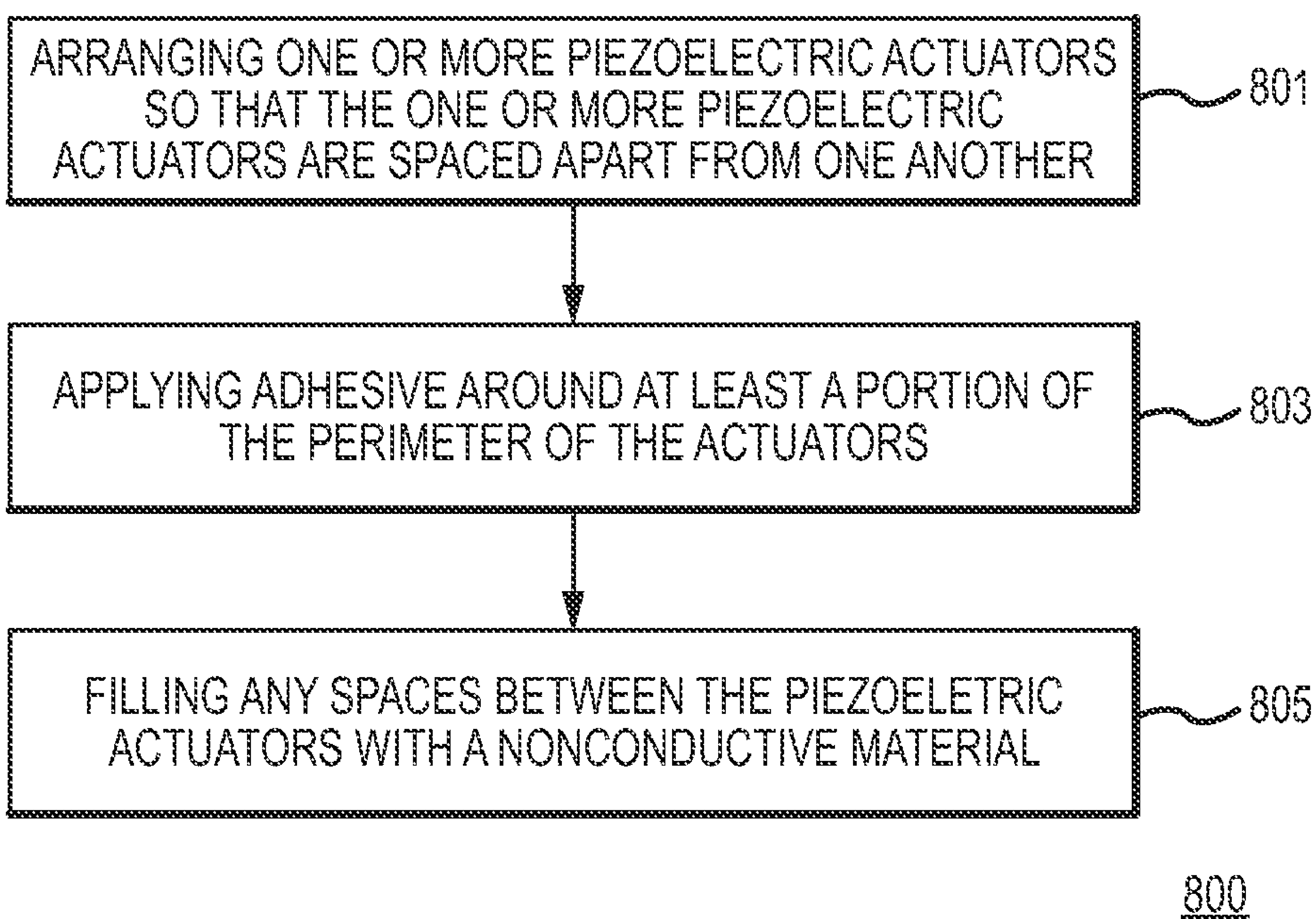

ARRANGING ONE OR MORE PIEZOELECTRIC ACTUATORS SO THAT THE ONE OR MORE PIEZOELECTRIC ACTUATORS ARE SPACED APART FROM ONE ANOTHER
801
APPLYING ADHESIVE AROUND AT LEAST A PORTION OF THE PERIMETER OF THE ACTUATORS
803
FILLING ANY SPACES BETWEEN THE PIEZOELETRIC ACTUATORS WITH A NONCONDUCTIVE MATERIAL
805
800

FIG.8

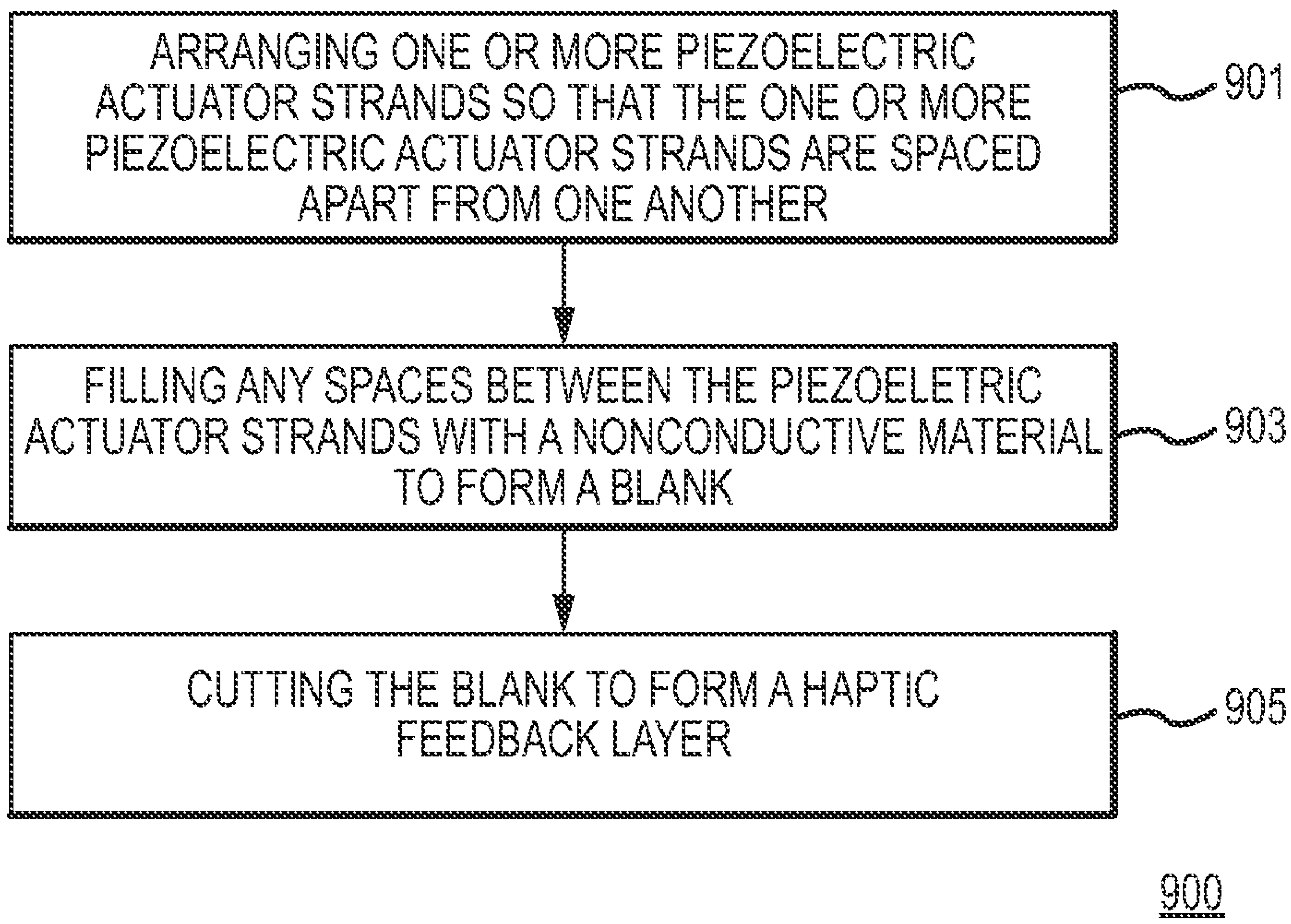

ARRANGING ONE OR MORE PIEZOELECTRIC ACTUATOR STRANDS SO THAT THE ONE OR MORE PIEZOELECTRIC ACTUATOR STRANDS ARE SPACED APART FROM ONE ANOTHER
901
FILLING ANY SPACES BETWEEN THE PIEZOELETRIC ACTUATOR STRANDS WITH A NONCONDUCTIVE MATERIAL TO FORM A BLANK
903
CUTTING THE BLANK TO FORM A HAPTIC FEEDBACK LAYER
905
900

FIG.9

TOUCH-BASED USER INTERFACE WITH HAPTIC FEEDBACK

BACKGROUND

I. Technical Field

Embodiments described herein relate generally to touch-based user interfaces, such as a track pad or a touch screen, and more particularly, to touch-based user interfaces capable of providing localized haptic feedback to a user.

II. Background Discussion

Existing touch-based user interfaces typically have a touch panel and a visual display component. The touch panel may include a touch sensitive surface that, in response to detecting a touch event, generates a signal that can be processed and utilized by other components of an electronic device. The touch sensitive surface may be separate from the display component, such as in the case of a trackpad, or may be integrated into or positioned in front of the viewable area of the display screen, such as in the case of a display touchscreen.

In either case, the display component may display textual and/or graphical display elements representing selectable virtual buttons or icons, and the touch sensitive surface may allow a user to navigate the content displayed on the display screen. Typically, a user may move one or more objects, such as a finger or a stylus, across the touch sensitive surface in a pattern that the device translates into an input command. As an example, some electronic devices allow the user to select a virtual button by tapping a portion of the touch sensitive surface corresponding to the virtual button. Other electronic devices include a touch sensitive surface that can detect more than one simultaneous touch events in different locations on the touchscreen.

Existing touch-based user interfaces do not provide haptic feedback to a user. Haptic feedback may be any type of tactile feedback that takes advantage of a user's sense of touch, for example, by applying forces, vibrations, and/or motions to the user. The user can typically only feel the rigid surface of the touch screen, making it difficult to find icons, hyperlinks, textboxes, or other user-selectable input elements that are being displayed. A touch-based user interface may help a user navigate content displayed on the display screen by incorporating haptic feedback. For example, localized haptic feedback can enable a user to feel what is being displayed by providing feedback when a user locates a virtual button, selects the virtual button and/or confirms the selection of the virtual button.

SUMMARY

Embodiments described herein relate to touch-based user interface devices that can both receive an input from a user and provide haptic feedback based on the input from the user. In one embodiment, a touch-based user interface device may include a haptic feedback layer that includes one or more piezoelectric actuators that are embedded in a nonconductive material. The haptic feedback layer may be the outermost layer of the touch-based user interface device so that the mechanical stimulation provided by the actuators can be felt by a user. However, in other embodiments, the haptic feedback layer may be covered by a protective coating or cover layer. In some embodiments, a printed circuit board layer may be positioned underneath the haptic feedback layer. The printed circuit board layer may include one or more metallic traces that are configured to supply a voltage to each of the piezoelectric actuators embedded in the haptic feedback layer. Some embodiments may also include input sensors, such as a displacement sensor and/or force sensor for recognizing and distinguishing between various touch-based input gestures from a user.

One embodiment may take the form of a touch-based user interface that includes a haptic feedback layer including one or more actuators configured to supply a haptic feedback. The one or more actuators may be embedded in a nonconductive material. The touch-based user interface may further include a printed circuit board layer underlying the haptic feedback layer. The printed circuit board layer may include one or more conductive traces configured to supply a voltage to the one or more actuators.

Another embodiment may take the form of a method for manufacturing a haptic feedback layer. The method may include arranging one or more piezoelectric actuators so that the one or more piezoelectric actuators are spaced apart from one another, and filing any spaces between the piezoelectric actuators with a nonconductive material.

Another embodiment may take the form of a method for manufacturing a haptic feedback layer. The method may include arranging one or more piezoelectric actuator strands so that the one or more piezoelectric actuator strands are spaced apart from one another, filling any spaces between the piezoelectric actuator strands with a nonconductive material to form a blank, and cutting the blank to form a haptic feedback layer.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1**A illustrates one embodiment of an electronic device that incorporates an embodiment of a touch-based user interface.

FIG. **1**B illustrates another embodiment of an electronic device that incorporates an embodiment of a touch-based user interface.

FIG. **1**C illustrates another embodiment of an electronic device that incorporates an embodiment of a touch-based user interface.

FIG. **2** illustrates a perspective view of a single piezoelectric actuator, as used in accordance with some embodiments.

FIG. **3**A illustrates a top down view of one embodiment of a touch-based user interface.

FIG. **3**B illustrates a side cross-sectional view of the touch-based user interface shown in FIG. **3**A, as taken along line **3**B-**3**B.

FIG. **4**A illustrates a top down view of one embodiment of a displacement sensor overlaying one or more piezoelectric actuators.

FIG. **4**B illustrates a close up and partially cut-away view of the embodiment shown in FIG. **4**A.

FIG. **4**C illustrates an exploded view of the embodiment shown in FIG. **4**A.

FIG. **5**A illustrates a top down view of another embodiment of a touch-based user interface.

FIG. **5**B illustrates a perspective view of the embodiment of the touch-based user interface shown in FIG. **5**A.

FIG. **6**A illustrates a perspective view of a sample embodiment shown in FIGS. **3**A and **3**B, shown during manufacturing of the embodiment before an adhesive is applied around the edges of the piezoelectric actuators.

FIG. **6**B illustrates a perspective view of the sample embodiment of FIGS. **3**A and **3**B, shown during manufacturing of the embodiment before nonconductive material is added to the mold.

FIG. 6C illustrates a perspective view of the sample embodiment of FIGS. 3A and 3B, shown during manufacturing of the embodiment after the spaces between the piezoelectric actuators have been filled with nonconductive material.

FIG. 7A illustrates a perspective view of the sample embodiments shown in FIGS. 3A and 3B and FIGS. 5A and 5B, shown during manufacturing of these embodiments from a composite blank before the composite blank is cut.

FIG. 7B illustrates a perspective view of a sample embodiment shown in FIGS. 3A and 3B, shown during manufacturing of the embodiment after the composite blank is cut.

FIG. 7C illustrates a perspective view of a sample embodiment shown in FIGS. 5A and 5B, shown during manufacturing of the embodiment after the composite blank is cut.

FIG. 8 is a flowchart setting forth a method for manufacturing a haptic feedback layer.

FIG. 9 is a flowchart setting forth a method for manufacturing a haptic feedback layer.

DETAILED DESCRIPTION

Embodiments described herein relate to touch-based user interface devices that can both receive an input from a user and provide haptic feedback based on the input from the user. In one embodiment, a touch-based user interface device may include a haptic feedback layer that includes one or more piezoelectric actuators that are embedded in a nonconductive material. The haptic feedback layer may be the outermost layer of the touch-based user interface device so that the mechanical stimulation provided by the actuators can be felt by a user. However, in other embodiments, the haptic feedback layer may be covered by a protective coating or cover layer. In some embodiments, a printed circuit board layer may be positioned underneath the haptic feedback layer. The printed circuit board layer may include one or more metallic traces that are configured to supply a voltage to each of the piezoelectric actuators embedded in the haptic feedback layer. Some embodiments may also include input sensors, such as displacement and/or force sensors for recognizing and distinguishing between various touch-based input gestures from a user.

The term "vertical" as used herein is defined as a plane perpendicular to the plane or surface of the haptic feedback layer, regardless of its orientation. The term "horizontal" refers to a direction perpendicular to the vertical direction just defined. Terms such as "above," "below," "bottom," "beneath," "top," "side," "higher," "lower," "upper," "over," and "under" (e.g., as in "underlying," "underneath," and so on) are defined with respect to the plane perpendicular to the plane or surface of the haptic feedback layer, regardless of its orientation. The term "outermost" refers to the surface positioned closest to a user engaging the surface. The term "outer," as in "outer surface," refers to any surface of an object, which can include the outermost surface.

FIGS. 1A-1C illustrate some examples of electronic devices that incorporate various embodiments of touch-based user interfaces. In one embodiment, shown in FIG. 1A, a laptop 111 may incorporate a trackpad 104 that serves as a user input-output (I/O) device. The trackpad 104 may be separate from the display screen 103 of the laptop 100.

As will be further described below, the trackpad 104 may include one or more input sensors that allow a user to interact with the laptop 111, as well as a surface capable of providing dynamic localized haptic feedback. In one embodiment, the trackpad 104 may be configured to sense various touch-based input gestures, such as swiping, taping, scrolling, and so on, applied across the surface of the trackpad 104. The touch-based input gestures may be applied by an object, such as a finger, a stylus, and so on. The input sensors may obtain information regarding the sensed gestures and transmit the information to a processing device provided in the laptop 111, which may translate the received information to a particular input command. As an example, the input sensors may derive distance and/or direction information regarding a sensed gesture, and the processing device may move a graphical pointer on the screen based on the received distance and/or direction information. As another example, the input sensors may be configured to sense a particular motion or pattern of motions and associate the sensed motion with a particular command. For example, a tap may be associated with a mouse click, while sliding the object along the trackpad in a particular manner may be associated with scrolling. The processing device may be any known processing device, including, but not limited to, a central processing unit (CPU), a microprocessor, a digital signal processor (DSP), a microcontroller, a graphics processing unit (GPU), and so on.

As discussed above, the trackpad 104 may be configured to provide haptic feedback based on the input gestures from the user. The haptic feedback may be used to enhance the user's interaction with the laptop 111 by providing mechanical stimulation to the user when the user is engaging the trackpad 104. For example, the haptic feedback may confirm the user's selection of a particular virtual icon or button, or may be provided when the user's cursor passes a selectable icon or button. Other embodiments may include other ways of providing haptic feedback to the user. The haptic feedback may be provided by one or more actuators configured to apply forces, vibration, and/or other motions to the object engaging the trackpad 104. As will be further discussed below, in one embodiment, the actuators may be distributed throughout the surface of the trackpad 104 so that a user may receive the feedback from different portions of the trackpad 104. In other embodiments, the actuators may only provided in certain sections of the surface of the trackpad 104, so that the user may only receive feedback when engaging those sections. As will be discussed below, the actuators may be piezoelectric actuators.

FIG. 1B illustrates another embodiment, in which the touch-based user interface may be incorporated into the housing of a mouse 108. One example of an existing mouse 108 incorporating such a touch-based user interface is Apple Inc.'s Magic Mouse™. The mouse 108 may include one or more sensors for detecting various touch-based input gestures, such as swiping, taping, single and two-finger scrolling, and so on, across the top surface 107 of the mouse 108 for allowing a user to interact with a desktop computer 105. In one embodiment, the top surface 107 of the mouse 108 may include a number of actuators that may provide haptic feedback to the user based on the user's interactions with the desktop computer 105. Like the trackpad 104 of the embodiment shown in FIG. 1A, the mouse 108 may be separate from the display screen 102 of the desktop computer 105.

In yet another embodiment, illustrated in FIG. 1C, the touch-based user interface may take the form of a touchscreen input component 106. The touchscreen input component 106 may be provided on an electronic device 101 that can function as, for example, a media device, a communications device, a digital camera, a video camera, a storage device, or any other electronic device. Some examples of electronic devices 101 incorporating touch-based user interfaces include Apple Inc.'s iPhone™ and iPad™. The electronic device **101** may include one or more sensors for detecting various touch-based input gestures, such as swiping, taping, scrolling, and so on, across a surface **109** overlaying the display screen of the electronic device **101** for allowing a user to interact with the device. In some embodiments, the surface **109** may include a number of actuators that may provide haptic feedback in response to the input gestures from the user.

FIG. **2** shows a perspective view of a single piezoelectric actuator **100**, as used in accordance with some embodiments. As discussed above, the piezoelectric actuator **100** may provide some type of mechanical stimulation, such as a pulse, vibration, or other feedback, upon actuation. The surface area of actuator **100** can be, for example, 10 square millimeters, 10 square micrometers, 10 square nanometers, or any other size that is physically possible. Additionally, while the illustrated piezoelectric actuator **100** has a rectangular configuration, other embodiments may be other shapes. For example, the piezoelectric actuator may be circular, ovular, triangular, elongated strands, and so on and so forth.

The piezoelectric actuator **100** may include electrodes **102** and **104** and piezoelectric material **106**, any or all of which can be transparent, opaque, or a combination thereof. The piezoelectric material **106** can include, for example, a ceramic, polyvinylidene fluoride, one or more natural crystals (such as, e.g., Berlinite, cane sugar, quartz, Rochelle salt, topaz, and/or any tourmaline group mineral(s)), man-made crystals (such as, e.g., Gallium orthophosphate or langasite), bone, polymers, and/or any other material that is able to mechanically deform in response to an applied voltage.

The piezoelectric material **106** may be connected to two electrodes **102** and **104**. One of the electrodes **102** may be connected to a positive terminal of a voltage source and the other of the electrodes **104** may be connected to a negative terminal of a voltage source. When a sufficient voltage is applied across the electrodes **102** and/or **104**, the piezoelectric material **106** can expand or contract in height (H). In other embodiments, the piezoelectric actuator **100** can be made to expand in other directions, such as in width, as opposed to height. The amount of voltage required to deform the piezoelectric material **106** may vary, and may depend on the type of piezoelectric material **106** used to manufacture the piezoelectric actuator **100**. When no voltage is supplied by the voltage source, or when the voltage across the electrodes **102**, **104** is less than the threshold amount of voltage required to deform the piezoelectric material **106**, the piezoelectric material **106** may return to its original dimensions (i.e., the dimensions of the material in its undeformed state).

The magnitude of expansion or contraction of the piezoelectric material **106** may be determined by the level or amount of voltage across the electrodes **102**, **104**, with a larger amount of voltage corresponding to a higher magnitude of expansion or contraction. Additionally, the polarity of the voltage across the piezoelectric material **106** may determine whether the piezoelectric material **106** contracts or expands. For example, the piezoelectric material **106** may expand in response to a positive voltage and contract in response to a negative voltage. Alternatively, the piezoelectric material may contract in response to a positive voltage and expand in response to a negative voltage.

In one embodiment, the piezoelectric actuator **100** can be made to vibrate by applying a control signal to one or both of the electrodes **102** and **104** of the piezoelectric actuator **100**. The control signal may be a wave having a predetermined amplitude and/or frequency. When the control signal is applied to one or both of the electrodes **102**, **104**, the piezoelectric actuator **100** may vibrate at the frequency of the control signal. The frequency of the control signal may be adjusted according to various embodiments to alter the rate of expansion and contraction of the piezoelectric actuators **100** if a more or less rapid vibration is desired. The amplitude of the control signal may be correlated to the magnitude of expansion or contraction of the piezoelectric material **106**, and may be adjusted to alter the intensity of the vibration.

FIG. **3**A illustrates a top down view of one embodiment of a touch-based user interface **300**. A cross-sectional view of the touch-based user interface **300** shown in FIG. **3**A is illustrated in FIG. **3**B. As shown in FIGS. **3**A and **3**B, the touch-based user interface **300** may include an optional cover layer **305**, a haptic feedback layer **301**, a printed circuit board ("PCB") layer **307**, and one or more force sensors **315**. In one embodiment, the optional cover layer **305** may be positioned above the haptic feedback layer **301**, the PCB layer **307** may be positioned below the haptic feedback layer **301**, and the force sensors **315** may be positioned below the PCB layer **307**. Other embodiments may include other arrangements of the haptic feedback layer **301**, the PCB layer **307**, force sensors **315** and cover layer **305**. For example, in one embodiment, the haptic feedback layer **301** may be positioned underneath the PCB layer **307**. Another embodiment may not include a cover layer **305**. Instead, the haptic feedback layer **301** may form the outermost surface of the touch-based user interface **300**. In a further embodiment, the force sensors **315** may be positioned above the haptic feedback layer **301**.

In one embodiment, the haptic feedback layer **301** may include one or more piezoelectric actuators **100** embedded in a nonconductive material **311**. Each of the piezoelectric actuators **100** in the haptic feedback layer **301** may be the same as or similar to the piezoelectric actuator **100** shown and described in FIG. **2**. In one embodiment, each piezoelectric actuator **100** may be individually controlled. In other embodiments, two or more piezoelectric actuators **100** can be grouped together and controlled as a single entity. For example, two or more piezoelectric actuators can be grouped together to represent a single virtual button. In further embodiments, any number of piezoelectric actuators **100** can be grouped to form a single entity.

One skilled in the art will appreciate that, despite the actuators shown in FIGS. **3**A and **3**B having the same physical dimensions, the piezoelectric actuators can be any size, or combination of sizes. For example, the piezoelectric actuators can be larger around the edges of the touch-based user interface **300** and proportionately smaller towards the middle of the touch-based user interface **300**. One skilled in the art would also appreciate that the space between piezoelectric actuators and/or the piezoelectric actuators' piezoelectric material can also be adjusted accordingly.

As shown in FIGS. **3**A and **3**B, the piezoelectric actuators **100** may be embedded into the haptic feedback layer **301** in any configuration. For example, as shown in FIG. **3**A, the piezoelectric actuators **100** may be arranged in a grid configuration to form a plurality of rows and columns. The number of rows and columns of piezoelectric actuators **100** on the touch-based user interface **300** may vary according to different embodiments. For example, one embodiment may include more rows than columns, while another embodiment may include equal numbers of rows and columns, and so on and so forth.

The piezoelectric actuators **100** may be embedded in a nonconductive material **311** that may serve to insulate the actuators **100** and separate the actuators **100** from one another. The nonconductive material **311** may be an inorganic or rigid material that has a sufficiently high modulus of rigidity to resist deformation when the embedded piezoelectric actuators **100** deform in response to a supplied voltage. In this embodiment, the nonconductive material **311** may maintain the same dimensions as the attached actuators **100** increase and decrease in height relative to the nonconductive material **311**. Some examples of inorganic materials that may be used include glass, ceramic, plastic, and so on and so forth. In other embodiments, the nonconductive material **311** may be an organic or compliant material that has a sufficiently high modulus of elasticity to deform with the attached embedded piezoelectric actuators **100**. In this embodiment, the nonconductive material **311** may increase and decrease in height as the attached embedded actuators **100** increase and decrease in height. Some examples of organic materials that may be used include elastomers, silicon, thermoplastics, and so on and so forth.

In one embodiment, the piezoelectric actuators **100** may be bonded to the nonconductive material **311** by an adhesive **308**. For example, the adhesive **308** may be applied around at least a portion of the perimeter of the piezoelectric actuators **100** to bond the actuators to the nonconductive material **311**. In some embodiments, the adhesive **308** may have a high modulus of elasticity so as to allow the piezoelectric actuators **100** to move relative to the nonconductive material **311** while resisting debonding of the actuators **100** and the nonconductive material, as well as cracking or wear of the adhesive itself. Some examples of suitable adhesives include, but are not limited to, a thermoplastic adhesive, a hot melt adhesive, a solvent-based adhesive, and so on and so forth.

The properties of the adhesive **308** may vary according to the properties of the nonconductive material **311** used to form the haptic feedback layer **301**. For example, an adhesive having a higher modulus of elasticity may be more suitable for embodiments utilizing a rigid nonconductive material **311** that resists deformation as the embedded piezoelectric actuators **100** are deformed. In contrast, an adhesive having a lower modulus of elasticity may be more suitable for embodiments utilizing a compliant or elastic nonconductive material **311** that is deformed with the embedded piezoelectric actuators **100**.

As discussed above, a PCB layer **307** may be positioned underneath the haptic feedback layer **301**. The PCB layer **307** may include a nonconductive matrix **309** configured to support the electrodes **102**, **104** corresponding to each of the piezoelectric actuators **100**. As shown in FIG. 3B, in one embodiment, each pair of electrodes **102**, **104** may be positioned directly beneath a corresponding piezoelectric actuator so that each of the electrodes **102**, **104** is aligned with a corresponding actuator **100** along at least one vertical axis. However, in other embodiments, the electrodes may not be vertically aligned with a corresponding actuator **100**. For example, in one embodiment, one or both of the electrodes **102**, **104** may be positioned to one side of a corresponding actuator **100**.

In one embodiment, the electrodes **102**, **104** may take the form of conductive metallic traces that are embedded within the nonconductive matrix **309**. As shown in FIG. 3B, the top ends of the metallic traces may contact the piezoelectric actuators **100**, and the metallic traces may extend from a top surface **312** of the PCB layer **307** through a bottom surface **314** of the PCB layer. The metallic traces may be formed from any suitable electrically conductive material, including, but not limited to, copper, aluminum, silver, gold, iron, and so on and so forth. In other embodiments, the electrodes **102**, **104** may be insulated wires, rather than uninsulated traces.

The nonconductive matrix **309** may be formed from any non-conductive material, including an low-temperature co-fired ceramic, an elastomer-based polymer, glass, Teflon, and so on and so forth. In one embodiment, the nonconductive matrix **309** may be formed from a rigid or semi-rigid material that may provide structural support to the haptic feedback layer **301**. For example, the nonconductive matrix **309** may prevent the haptic feedback layer **301** from cracking when depressed. The nonconductive matrix **309** may completely surround each of the electrodes **102**, **104** so as to insulate the individual electrodes and prevent contact between adjacent electrodes. However, in other embodiments, such as where insulated wires are used rather than uninsulated traces, the nonconductive matrix **309** may only partially surround each of the electrodes **102**, **104**.

In some embodiments, the haptic feedback layer **301** may be fully or partially covered by an optional cover layer **305**. The optional cover layer **305** may serve to insulate and protect the haptic feedback layer **301** from wear. The cover layer **305** may be sufficiently thin so as to allow a user to feel the forces supplied by the actuators **100**. In one embodiment, the optional cover layer **305** may be formed from a transparent nonconductive material, such as glass, a clear cosmetic glaze, plastic, and so on. However, in other embodiments, the cover layer **305** may be formed from a fully or partially opaque material, such as a ceramic or an opaque paint. In another embodiment, the cover layer **305** may be a clear material that is sprayed or otherwise coated by an opaque paint. For example, the cover layer **305** may be a glass layer that is coated in paint.

As alluded to above, the touch-based user interface **300** may also include one or more force sensors **315**. In one embodiment, the force sensors **315** may be located beneath the PCB layer **307**. However, in other embodiments, the force sensors **315** may be positioned above the haptic feedback layer **301** or embedded into the PCB layer **307** or the haptic feedback layer **301**. The force sensors **315** may be capable of sensing the amount of force or pressure being exerted on the sensors. When a force is applied to the touch-based user interface **300**, the force may be transmitted through the outer layers of the interface to a force sensor underneath. Some examples of force sensors **315** that may be used in conjunction with the touch-based user interface may include, but are not limited to, force sensitive resistors, force sensitive capacitors, load cells, pressure plates, piezoelectric transducers, strain gauges, and so on and so forth.

In one embodiment, the force sensors **315** may be positioned underneath or incorporated into the outermost surface of the touch-based user interface **300**. In this embodiment, the outermost surface of the touch-based user interface **300** may allow for a slight amount of flex so that any forces on the surface can be distributed to a respective force sensor. Accordingly, when a force is applied to the touch-based user interface **300**, for example, due to squeezing or pushing on the outermost surface, the force may be transmitted through the outermost surface to a force sensor **315** located underneath the outermost surface. That is, the outermost surface may flex minimally, but still enough to be sensed by the force sensor **315** embedded in the outermost surface or sandwiched between the outermost surface and another intermediate layer of the touch-based user interface **300**.

The force sensors **315** may produce signals indicative of the sensed forces. In one embodiment, the sensors **315** may be configured to generate input signals when forces are applied to the touch-based user interface **300**. The processing device of the electronic device may then process the input signals to distinguish between various touch-based input gestures and initiate commands according to the different input gestures. Accordingly, the force sensors **315** may allow for distinguishing between various input gestures that may be associated with different commands. In one embodiment, the force sensors may be used to differentiate between a click and a scroll command. As an example, the processing device may associate a higher amount of force, such as from a tapping motion, with a click command and a lower amount of force, such as from a gliding motion, with a scroll command (or vice versa). Accordingly, if the force measured by the force sensors **315** is over a threshold level of force, the input gesture may be interpreted as a click command. On the other hand, if the force measured by the force sensors **315** is less than the threshold level of force, the input gesture may be interpreted as a scroll command.

The touch-based user interface **300** may also include a displacement sensor that may derive spatial data relating to the position of the object on the interface, as well as proximity data relating to the distance of the object from the interface. In one embodiment, illustrated in FIGS. **4A-4C**, the displacement sensor may be a capacitance sensor **320** that can detect the location of a finger (or other object) using mutual capacitance sensing. In one embodiment, the capacitance sensor **320** may be incorporated into the PCB layer **307** underlying the haptic feedback layer **301**. However, in another embodiment, the capacitance sensor **320** may be sandwiched between the haptic feedback layer **301** and the PCB layer **307**. In other embodiments, the capacitance sensor **320** may be incorporated into any layer of the touch-based user interface **300** described above, or may be an additional layer that is positioned above or below the other layers of the interface **300** or sandwiched between two layers of the interface **300**.

In one embodiment, the capacitance sensor **320** may include electrically conductive electrodes **335** that are deposited in varying patterns onto two flexible substrate sheets **331**, **333**. The substrate sheets **331**, **333** may be formed from a flexible, yet rigid nonconductive material, such as plastic, polyester, rubber, glass, and so on and so forth. In one embodiment, the electrodes **335** may be deposited on the inner surface of one sheet **331** to form a row pattern, and on the corresponding inner surface of the other sheet **333** to form a column pattern. The spacing between the rows **338** and columns **339** may vary according to different embodiments, with a smaller spacing size corresponding to a more sensitive capacitive sensor **320**. When the two substrate sheets are positioned with one on top of the other with the electrodes facing one another, a grid pattern may be formed. A finger, or other object, placed near the intersection **336** of two electrodes modifies the capacitance between them. This change in capacitance can be measured, and the position of the finger may be determined based on these changes at various points along the capacitance sensor.

In one embodiment, the piezoelectric actuators **100** may be embedded in the haptic feedback layer **301** so that the actuators **100** are aligned with the grid pattern formed by the electrodes **335** of the capacitance sensor **320**. For example, the piezoelectric actuators **100** may be positioned above the spaces **322** defined between the rows **338** and columns **339** of the grid so that the spaces **322** and the actuators **100** are aligned along at least one vertical axis. As a change in capacitance is detected at a particular intersection **336** or group of intersections, a voltage may be supplied to the actuator **100** or group of actuators positioned proximate the intersections **336**. The piezoelectric actuators **100** may or may not be positioned above every space of the grid. For example, a single piezoelectric actuator **100** may be provided for every other space of the grid or every third space of the grid. In another embodiment, multiple piezoelectric actuators **100** may be provided for some spaces.

As discussed above, the haptic feedback from the piezoelectric actuators **100** may allow for enhanced navigation of the content displayed on a display coupled to the touch-based user interface. In one embodiment, the piezoelectric actuators **100** may replace the mechanical "click" of a mouse, trackpad, or other user interface of an electronic device. For example, the touch-based user interface may confirm a "click" by supplying a voltage to the piezoelectric actuators **100** so that the user feels a vibration or other motion. In one embodiment, the electronic device may interpret a tapping motion on the surface of the touch-based user interface as corresponding to a click command. In contrast, when the user glides a finger or other object along the surface of the touch-based user interface, the piezoelectric actuators **100** may remain unactuated. Accordingly, a user may be able to ascertain whether the electronic device has interpreted an input gesture as a click or a scroll.

In another embodiment, the piezoelectric actuators **100** may allow the user "feel" the selectable buttons or icons displayed by the electronic device. This embodiment may be particularly useful in a touch-based user interface that is not overlaid on a display screen, such as a trackpad or a mouse, in which the user cannot position a finger or other object directly over the displayed buttons and icons to select them. In one implementation, a voltage may be supplied to the piezoelectric actuators **100** when a cursor is positioned within selection range of a virtual button or icon. Accordingly, the user may feel a vibration or other motion indicating that the user may select the button with a selection input gesture.

FIGS. **5A** and **5B** illustrate a top down view and a perspective view of another embodiment of a touch-based user interface **200**. In this embodiment, the piezoelectric actuators **201** may take the form of one or more strands **203** that extend laterally across the haptic feedback layer **205**. In one embodiment, the strands **203** may be parallel to one another, and may extend in a horizontal direction across the haptic feedback layer **205**. In this embodiment, the electrically conductive traces connected to the strands **203** may be positioned on the sides of the haptic feedback layer **203**, as opposed to underneath the haptic feedback layer **203** as in the embodiment shown in FIGS. **3A** and **3B**. The strands **203** may be embedded in the nonconductive material **207** such that the strands **203** are exposed and form part of the outer surface of the haptic feedback layer **205**. Alternatively, the strands **203** may be covered by the nonconductive material **207**.

In other embodiments, the traces may be positioned underneath the strands **203**. In further embodiments, the strands **203** may not be parallel to one another, but may extend at angles with respect to one another. Additionally, the strands **203** may extend vertically or diagonally across the haptic feedback layer **205**, rather than horizontally.

FIGS. **6A-6C** illustrate one embodiment of a method for manufacturing a haptic feedback layer. In a first step, illustrated in FIG. **6A**, one or more piezoelectric actuators **100** may be arranged in a mold **160**. The mold **160** may define the shape of the formed haptic feedback layer. The actuators **100** may be arranged in any configuration. For example, the actuators **100** may be evenly spaced apart in the mold **160**, or concentrated in one portion of the mold. The actuators **100** may have any shape. For example, the actuators may have a circular shape, a square shape, a triangular shape, or any other shape. The actuators may all be substantially identical, or some actuators may have a different configuration than other actuators.

In a second step, illustrated in FIG. **6**B, an adhesive **308** may be applied around all or a portion of the perimeter of the piezoelectric actuators **100**. As discussed above, the adhesive **308** may bind the piezoelectric actuators **100** to the nonconductive material. In one embodiment, the adhesive **308** may be a hot melt adhesive that is applied around the perimeter of the actuators. Other embodiments may use other types of adhesive, as discussed above. In an alternate embodiment, the adhesive **308** may be applied after the nonconductive material is added to the mold. For example, the actuators **100** may be spaced apart from the nonconductive material, and the adhesive may be added after nonconductive portion of the blank is formed. Additionally, some embodiments may not include an adhesive layer between the nonconductive material and the piezoelectric actuators **100**. Accordingly, the adhesive application step described above is optional.

In a third step, illustrated in FIG. **6**C, a nonconductive material **311** may added to the mold to fill the spaces between the piezoelectric actuators **100**. In one embodiment, the nonconductive material **311** may be heated to a liquid form and then poured into the mold **160** to fill the spaces between the actuators **100**. In another embodiment, the nonconductive material **311** may be added to the mold **160** in solid form, and the actuators and the nonconductive material may be heated to melt the nonconductive material **311** so that it fills the spaces between the actuators **100**. After the nonconductive material **311** is added to the mold **160**, the composite layer may be heated, baked, or otherwise processed to form the final haptic feedback layer **301**.

In one embodiment, both the nonconductive material and the actuators may each define a portion of the outer surface of the haptic feedback layer. However, in other embodiments, the nonconductive material **311** may cover all or part of the actuators **100** to form one or more of the side, top and/or bottom surfaces of the haptic feedback layer. Accordingly, in one embodiment, the nonconductive material may define the outer surfaces of the haptic feedback layer, or the actuators may define a portion of one outer surface of the haptic feedback layer, while the other surfaces are defined by the nonconductive material.

FIGS. **7**A-**7**C illustrate another embodiment of a method for manufacturing a haptic feedback layer. In particular, FIG. **7**A illustrates a perspective view of a composite blank **700** that may be used to form a haptic layer of a touch-based user interface. As shown in FIG. **7**A, the composite blank may include one or more piezoelectric strands **201** that are conjoined with a nonconductive material **311**. The strands **201** may have any cross-sectional configuration. For example, the strands may have a circular cross-section, a rectangular cross-section, a square cross-section, a triangular cross-section, and so on and so forth. In one embodiment, the piezoelectric strands may be parallel to one another such that the strands form one or more rows and one or more columns within the composite blank. However, in other embodiments, the piezoelectric strands may extend at angles from one another. As discussed above, the side surfaces of the piezoelectric strands may be joined to the nonconductive material by an adhesive material **308**.

The composite blank **700** may be formed in a manner similar to that described with respect to the method for forming a haptic layer illustrated in FIGS. **6**A-**6**C. That is, the composite blank **700** may be formed by arranging the piezoelectric strands **201** in an array configuration, and then filling the spaces between the strands with a nonconductive material **311**. The array of strands may first be arranged in a mold defining the shape of the blank.

As discussed above, the spaces between the strands of the array may then be filled with the nonconductive material **311**. In one embodiment, the nonconductive material **311** may be heated to a liquid state, and then poured over the array of piezoelectric strands **201**. In other embodiments, the nonconductive material, in solid form, may be placed around the piezoelectric strands, and the strands and the nonconductive material may be heated so that the nonconductive material is melted and fills the gaps between the strands. In one embodiment, adhesive **308** may be applied to the side edges of the strands before the nonconductive material is added to the mold.

The formed composite blank **700** may then be cut to form different configurations of touch-based user interface devices. In one embodiment, shown in FIG. **7**B the blank may be cut along a plane perpendicular to the direction of extension of the strands to form a haptic feedback layer **301** similar to that shown in FIGS. **3**A and **3**B, with the shape of the piezoelectric actuators **100** varying according to the cross-sectional profile of the strands **201**. The blank may be cut using, for example, a computer-numerical controlled laser cutting tool, or alternatively, a mechanical cutting tool such as a blade. In another embodiment, shown in FIG. **7**C, the blank **700** may be cut along a plane parallel to the direction of extension of the strands **201** form a haptic feedback layer **205** similar to that shown in FIGS. **5**A and **5**B. For example, the blank may be cut along the nonconductive areas between the strands so that the piezoelectric strands of the resulting touch-based user interface are covered by the nonconductive material. Alternatively, the blank may be cut to expose the strands **201** so that the strands form at least part of the outer surface of the resulting haptic feedback layer **205**.

FIG. **8** is a flowchart illustrating one embodiment of a method **800** for manufacturing a haptic feedback layer. For example, the illustrated method **800** may be used to form an embodiment similar to that shown in FIGS. **3**A and **3**B. The method **800** may begin by arranging one or more piezoelectric actuators in a spaced-apart configuration, as indicated in block **801**. As discussed above, the mold may define the shape of the formed haptic feedback layer. The actuators may be arranged in any configuration. For example, the actuators may be evenly spaced apart in the mold, or concentrated in one portion of the mold.

An adhesive may then be applied around at least a portion of the perimeter of the piezoelectric actuators, as indicated in block **803**. As discussed above, the adhesive may bind the piezoelectric actuators to the nonconductive material. In some embodiments, the adhesive may have a high modulus of elasticity so as to allow the piezoelectric actuators to move relative to the nonconductive material while resisting debonding of the actuators and the nonconductive material, as well as cracking or wear of the adhesive itself.

The spaces between the actuators may be filled with a nonconductive material, as indicated in block **805**. As discussed above, in one embodiment, the nonconductive material may be heated into liquid form and poured into the mold to fill the spaces between the actuators. In other embodiments, the nonconductive material may be inserted into the mold in solid form, and the actuators and the nonconductive material may be heated so that the nonconductive material fills the spaces between the actuators.

FIG. **9** is a flowchart illustrating another embodiment of a method **900** for manufacturing a haptic feedback layer. For example, the illustrated method **900** may be used to form embodiments similar to that shown in FIGS. **3**A and **3**B and FIGS. **5**A and **5**B. The method **900** may begin by arranging one or more piezoelectric strands in a spaced-apart configuration, as indicated in block **901**. As discussed above, the spacing between the strands and the configuration of the strands may vary according to different embodiments. The strands may first be arranged in a mold defining the shape of the blank. The spaces between the strands may then be filled with a nonconductive material to form a composite blank, as indicated in block **903**. As discussed above, the nonconductive material may be heated into liquid form and poured into the mold to fill the spaces between the strands. In other embodiments, the nonconductive material may be inserted into the mold in solid form, and the strands and the nonconductive material may be heated so that the nonconductive material fills the spaces between the strands.

The composite blank may then be cut, as indicated in block **905**. As discussed above, in one embodiment, the composite blank may be cut along a plane perpendicular to the direction of extension of the strands. In another embodiment, the composite blank may be cut along a plane parallel to the direction of extension of the strands so that the formed haptic feedback layer includes one or more strands extending across it. The strands may be exposed, so that the strands form a portion of the outermost surface of the haptic feedback layer, or may be covered by the nonconductive material.

The order of execution or performance of the methods illustrated and described herein is not essential, unless otherwise specified. That is, elements of the methods may be performed in any order, unless otherwise specified, and that the methods may include more or less elements than those disclosed herein. For example, it is contemplated that executing or performing a particular element before, contemporaneously with, or after another element are all possible sequences of execution.

The invention claimed is:

1. A touch-based user interface, comprising:
- a haptic feedback layer comprising a layer of nonconductive material and one or more actuators embedded within the layer of nonconductive material, the one more actuators configured to supply a haptic feedback;
- one or more force sensors configured to differentiate among a plurality of input commands based, at least in part, on an amount of force sensed by the one or more force sensors; and
- a printed circuit board layer, disposed on a first side of the haptic feedback layer, and positioned between the haptic feedback layer and the one or more force sensors, the printed circuit board layer including one or more conductive traces configured to supply a voltage to the one or more actuators, wherein
- a second side of the haptic feedback layer opposite to the first side is positioned toward an outermost surface of the touch-based user interface.

2. The touch-based user interface of claim **1**, wherein at least one of the one or more actuators is a piezoelectric actuator.

3. The touch-based user interface of claim **1**, wherein the printed circuit board layer further comprises a capacitive sensor.

4. The touch-based user interface of claim **3**, wherein the capacitive sensor includes a first layer of electrodes and a second layer of electrodes, the first layer of electrodes overlaying the second layer of electrodes to form a grid defining one or more spaces between the first layer of electrodes and the second layer of electrodes.

5. The touch-based user interface of claim **4**, wherein at least one of the one or more actuators is aligned along at least one vertical axis with at least one of the one or more spaces of the grid.

6. The touch-based user interface of claim **1**, wherein the one or more force sensors are positioned underneath the printed circuit board layer.

7. The touch-based user interface of claim **1**, wherein the one or more actuators forms at least a portion of an outer surface of the haptic feedback layer.

8. The touch-based user interface of claim **1**, wherein the one or more actuators is joined to the nonconductive material by an adhesive.

9. The touch-based user interface of claim **1**, wherein at least one of the one or more actuators is configured to move independently from another actuator of the one or more actuators.

10. The touch-based user interface of claim **1**, wherein the one or more actuators form rows of actuators that extend laterally across the haptic feedback layer.

11. The touch-based user interface of claim **1**, further comprising a cover layer overlaying the haptic feedback layer.

12. The touch-based user interface of claim **1**, wherein the nonconductive material has a modulus of rigidity to prevent the nonconductive material from moving relative to the one or more actuators when a voltage is supplied to the one or more actuators.

13. A method for manufacturing a haptic feedback layer, comprising:
- arranging one or more piezoelectric actuator strands so that each of the one or more piezoelectric actuator strands are spaced apart from one another;
- melting a nonconductive material to form a liquid;
- filling spaces between the piezoelectric actuator strands with the melted nonconductive material to form a blank so that the piezoelectric actuator strands are embedded within the nonconductive material;
- cutting the blank to form a haptic feedback layer;
- orienting one side of the haptic feedback layer toward a first side of a printed circuit board layer; and
- coupling one or more force sensors to a second side of the printed circuit board layer that is opposite to the first side, wherein the one or more force sensors are configured to differentiate among a plurality of input commands based, at least in part, on an amount of force detected by the one or more force sensors.

14. The method of claim **13**, wherein the blank is cut along a plane perpendicular to a direction of extension of the piezoelectric actuator strands.

15. The method of claim **13**, wherein the blank is cut along a plane parallel to a direction of extension of the piezoelectric actuators strands.

16. The method of claim **15**, wherein the blank is cut such that only the nonconductive material between the piezoelectric actuator strands is cut.

17. A touch-based input device, comprising:
- one or more actuators embedded within a layer of nonconductive material and configured to supply a haptic feedback; and

one or more force sensors embedded within a printed circuit board layer and configured to differentiate among a plurality of input commands based, at least in part, on an amount of force sensed by the one or more force sensors;

wherein the printed circuit board layer is attached to the layer of nonconductive material and comprises one or more conductive traces that supply a voltage to the one or more actuators, and the layer of nonconductive material is positioned toward an outermost surface of the touch-based user interface.

18. The touch-based input device of claim **17**, wherein the outermost surface of the touch-based input device is configured to flex in response to a received force.

19. The touch-based input device of claim **17**, wherein a first input command of the plurality of input commands is associated with a first gesture and a second input command of the plurality of input commands is associated with a second gesture.

20. The touch-based user interface of claim **4**, wherein the capacitive sensor measures a change in capacitance at a location at which a first electrode of the first layer of electrodes crosses above a second electrode of the second layer of electrodes.

* * * * *